ATTACHMENT 3

Investigation of Regional Regression Equations for Flow Duration, Peak and Annual Maximum Flow, and Low-flow Frequency Curves for the Lake Tahoe Basin

LAKE TAHOE, CALIFORNIA AND NEVADA

Prepared for:

SWQIC
Lake Tahoe Storm Water Quality Improvement Committee

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Executive Summary

a) The purpose of this report is to describe the regional analysis used to develop regression equations for predicting annual peak and volume duration frequency curves, 7day low-flow, and flow duration frequency curves for the Lake Tahoe Basin. These regressions relate watershed and meteorologic parameters to quantile estimates (e.g., the 1% chance peak flow or 7day, 10year low flow) obtained from stream gage information.

b) The regional regression equations have the general form:

$$\log_{10}(Q_p)=b_0+b_1\log_{10}(x_1)+b_2\log_{10}(x_2)+.....e$$

where: Q_p, a dependent variable, is the flow quantile obtained from a flow frequency curve (e.g., the 1% chance exceedance (100 year) flow or 7day, 10year low flow), x_1, x_2 are independent regression parameters such as drainage area or mean annual precipitation, b_0,b_1,b_2 are regression constants and e is a residual error representing the inability of the regression model to explain the variation in the dependent variable. Ordinary, weighted and generalized least squares were used to determine the regression coefficients given data on watershed characteristics, x_i, and Q_p, which is estimated from frequency analysis of flow records, for gaged watersheds.

c) The regional regressions were developed to address traditional drainage and best management practice design problems, provide measures of stream flow characteristics for restoration design and estimates of critical low-flow periods for meeting regulatory water quality requirements.

d) The regression equations should be limited to: 1) natural/open drainage areas > 0.5 sq mi, basins; 2) where a significant portion of drainage area exceeds 7000 ft msl; and 3) should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50 or urban areas. This minimum drainage area limits the applicability of these equations to drainage and best management practice design problems which usually focus on much smaller drainage areas. However, the equations will be very valuable for comparing/verifying/calibrating watershed models of ungaged areas.

e) The study included gages from a region: 1) where the hydrology and meteorology is similar to that of the Lake Tahoe Basin.

f) The watershed and meteorologic characteristics (the x_i needed to estimate regression equation parameters) were developed using GIS based technology to compute gage drainage area average characteristics. Drainage areas and mean elevation data were computed using digital elevation data obtained from the U.S. Geological Survey. Drainage area mean annual precipitation, temperature and annual snowfall data were estimated from an application of the PRISM model (Taylor et al., 1993). Precipitation depth-duration-frequency curve information was obtained by special request from the National Weather Service (Bonnin, personal communication, 2003).

g) Peak and daily stream flow gage data were obtained from the U.S. Geological Survey web-site. 38 regional and 36 Lake Tahoe Basin gages were examined for analysis. Various combinations of these gages were used depending on the record length of recorded peak and daily stream flows available for a particular analysis. In the case of low-flow and flow-duration analyses, gages were excluded due to significant effects of water supply diversions or reservoir regulation. Regulation rarely was a factor for the analysis of peak and high flows. Flow frequency curves were estimated from these gage records to obtain the quantiles, Q_p, needed to estimate regression coefficients.

h) Both a scaling approach and direct regression with quantiles was considered for developing the regional relationships. The scaling approach presumes that the flow frequency curves could be determined from a single dimensionless frequency curve multiplied by a scaling factor, such as drainage area. An investigation of flow-duration curves indicated that drainage area was not useful as a scaling parameter, but flow standard deviation might be useful. However, since a regression relation would be needed to relate standard deviation to basin characteristics, the decision was made to use the U.S. Geological Survey standard approach of relating basin characteristics and metorologic parameters directly to quantiles by regression rather than use the scaling approach.

i) Peak flow frequency analysis:
   - A standard Bulletin 17B analysis (see, IACWD 1982) was performed to obtain quantile estimates for the regional and Lake Tahoe Basin gages.
   - Estimating the peak flow quantiles at gage sites was complicated by the occurrence of the 1997 event. Many of the gages in the study area had relatively short record lengths (e.g., 10years). Although these record lengths are generally considered to be long enough for performing frequency analysis (see IACWD, 1982), applications at these gages resulted in a 1997 event with a plotting position value of about 1/10. This seemed unreasonable for an event that caused the largest outflow from Lake Tahoe in over 100 years. Additionally, this event was one of three major events (the others being 1986, and 1861) to impact the California Central valley, and the associated west sloping basins, occurring in the period of record beginning in 1861. Clearly, 1997 was a major regional event. To obtain a better estimate of the plotting position of the 1997 event the following assumptions were made:
     - At locations where the 1997 event was the maximum, it was given a historic ranking of 1/103 consistent with the period of record outflows for Lake Tahoe.
     - At locations where the 1997 event was not maximum, no historic weighting was provided for the plotting position.
   - Use of the historic weighting in this manner is only an approximation. High flows are caused by a mixture of winter events, like 1997, and spring-summer convective events. It is quite possible that unrecorded spring summer events in the past 103 years have exceeded the 1997 event. For example, the 1997 event was not the greatest flood of record in three of the 17 gages in the Tahoe Basin that had period of records including this event (see Table 6.1). Additionally, this event was the largest in 12 of 15 gages sin the region surrounding Lake Tahoe, including a period of record that begins in 1890 at one gage (see Table 6.2).
   - Ideally, a mixed distribution analysis of the peak flows would be performed to better capture the recurrence interval of the 1997 event. In a mixed analysis, peaks from different causative factors such as winter versus summer precipitation would be separately analyzed and then combined to obtain an annual frequency curve (see IACWD, 1982). In this type of analysis, the 1997 event would be given a historic weight for winter storms which is more defensible than giving it the historic weight in an annual analysis. Unfortunately, the data did not exist for peak flows to perform this mixed analysis.

- However, the mixed distribution analysis could be performed for 1day maximum flow values. As can be seen from Table 6.5, the exceedance probability estimates for the 1997 event are reasonably consistent between the peak and 1-day analysis.
- Providing the historic weighting to the 1997 event does lower the estimates of flood quantiles (e.g., provides lower values for the 1% chance exceedance (100 year) flow). At any particular gage, the assumed historic weighting may be in error. However, on the average, the overwhelming evidence is that the historic weighting of the 1997 events provides a better regional average estimate of Lake Tahoe Basin flow frequencies. Obtaining the best average estimate will be reflected in the regional regression equations.

j) Peak flow regional regression frequency curves

- The regression equations obtained for the region did not provide greater prediction accuracy then regression equations obtained using gages for the Lake Tahoe Basin alone. Consequently, only the Lake Tahoe Basin gages were used to develop the regression equations for peak and annual maximum volume duration frequency curves.
- Generalized least squares regression estimates for peak flows were obtained using the Lake Tahoe Basins as shown in the following table.
- The regression equation including mean annual precipitation (map) are recommended* over the regressions with mean annual snowfall because: 1) the regressions using map were nearly as accurate as those using snowfall; 2) MAP is easier to estimate than snowfall; and 3) the regressions result in more consistent estimates at the extremes of the range of regression applicability.
- Example applications can be found in SPK (2005).

* Recommendation revised - see Final Summary Report

Summary best regional regression for peak annual quantiles (see Table 6.11)
(*Regression equations should be limited to open land use drainage areas > 0.5 sq. mi., basins where a significant portion of drainage area exceeds 7000 ft. msl, should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50).*

[8]probability	constant (b_0)	[1]area (b_1)	[2]elevation (b_2)	[4]snow (b_3)	[5]se	[6]R^2	[7]avp
Best regression							
0.002	51.4905	1.0048	-14.1498	2.282	0.22	0.95	0.16
0.01	44.5481	0.9463	-12.4502	2.3831	0.19	0.96	0.15
0.02	41.0838	0.9222	-11.5941	2.4171	0.19	0.96	0.14
0.04	37.1691	0.9	-10.6206	2.4426	0.18	0.96	0.15
0.1	31.0127	0.874	-9.0837	2.4671	0.18	0.96	0.16
	constant (b_0)	[1]area (b_1)	[2]elevation (b_2)	[3]map (b_3)	[5]se	[6]R^2	[7]avp
Recommended regression							
[9]0.002	33.5078	1.1884	-9.3726	2.8118	0.29	0.91	0.20
0.01	23.3825	1.1254	-6.8861	3.0215	0.25	0.93	0.18
0.02	20.9166	1.0971	-6.3088	3.1346	0.22	0.94	0.17
0.04	16.8238	1.0678	-5.3176	3.2437	0.21	0.95	0.17
0.1	10.9192	1.0272	-3.8941	3.4092	0.19	0.96	0.16
0.2	5.7616	0.9957	-2.6617	3.5692	0.17	0.96	0.16

	constant (b_0)	[1]area (b_1)	[2]elevation (b_2)	[3]map (b_3)	[5]se	[6]R^2	[7]avp
0.50	-5.4765	0.9553	3.9699		0.16	0.97	0.14
0.80	-6.2034	0.9493	4.2644		0.16	0.97	0.15
0.90	-6.5624	0.9454	4.4023		0.19	0.96	0.15
0.95	-6.8580	0.9428	4.5149		0.23	0.95	0.16
0.99	-7.4826	0.9402	4.7821		0.35	0.90	0.19

(Regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50)

[1]drainage area (square miles), [2]mean annual precipitation (inches), [3]elevation (feet msl), [4]mean annual snowfall (inches), [5]standard error ($\log_{10}$), [6]multiple coefficient of determination (adjusted) R^2 ($\log_{10}$), [7]average prediction error ($\log_{10}$)

[8]best regression: (application limited to drainage areas > 0.5 sq miles, basin average elevation > 7000 (ft msl) see discussion.

$\log_{10}(Q_p)=b_0 + b_1\log_{10}(\text{area}) + b_2\log_{10}(\text{elevation}) + b_3\log_{10}(\text{snow})$ p=0.1 to 0.002

[9]recommended regression: application limited to drainage areas > 0.5 sq miles, basin average elevation > 7000 (ft msl) see discussion.

$\log_{10}(Q_p)=b_0 + b_1\log_{10}(\text{area}) + b_2\log_{10}(\text{elevation}) + b_3\log_{10}(\text{map})$ p=0.2 to 0.002

$\log_{10}(Q_p)=b_0 + b_1\log_{10}(\text{area}) + b_2\log_{10}(\text{map})$ p=0.5 to 0.99

(recommended regressions result in predictions **10% less** then best regression predictions over all gages used in study)

k) Comparison with other regression equations

- The Lake Tahoe peak annual flow regression predictions (Table 6.11)of the 1% peak annual flow were compared with those obtained from the regional gages (see Table 2.1), those available from the USGS (see, Blakemoore, et al., 1997) and from a study done by HYDMET (see Schively and Clyde, 2004). The USGS regressions used gages obtained from a much larger area than the Tahoe Basin used in this study, covering the southern range of the Sierra Nevada. Table 6.13 shows the gages used in the HYDMET study. The GLS regression using regional gages covers an area and number similar to that of the USGS study. Table 6.14 summarizes the source and relatively accuracy of the regression equations used in the comparison.

- The regression comparisons at the 1% exceedance peak annual discharges demonstrated large difference between the USGS and this study's estimates but agreement on the average in comparison of the HYDMET and this study's regression estimates (see Table below). The differences in predictions with regional gage regression estimates obtained in this study were significantly smaller than the USGS equations, but, still significant. The difference with the USGS regression predictions can be explained by the very different sources of data employed in both studies. The same probably can be said for the differences found in comparison with the regional gage regression equations. Although agreement was obtained on the average, there was a significant east-west location bias in the regression prediction differences with the HYDMET results. A sensitivity analysis of the Eagle Rock Creek gage peak annual frequency curve showed that the HYDMET regressions over predicted the 1% discharge for the eastern gages. The HYDMET smaller predictions in comparison with this study's regression prediction for the western gages are probably due to the lack of western gages used in the HYDMET analysis.

Comparison of regression equation estimates (see Table 6.15)

Location	USGS ID	area (sq-mi)	elevation (ft)	latitude (degrees)	[1]MAP (inches)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
UPPER TRUCKEE	10336580	14.09	8258.59	38.79630	51.9	768	423	-0.45	1485	0.93	790	0.03
UPPER TRUCKEE	10336600	33.1	8042.35	38.84296	50.4	2208	993	-0.55	3632	0.65	1666	-0.25
UPPER TRUCKEE	103366092	34.28	7996.26	38.84852	51.8	2595	1028	-0.60	4135	0.59	1737	-0.33
UPPER TRUCKEE	10336610	54.9	7614.23	38.92241	47.0	4605	1647	-0.64	6300	0.37	2883	-0.37
TAYLOR	10336626	16.7	7598.62	38.92157	50.9	1557	501	-0.68	2342	0.50	1141	-0.27
LAKE TAHOE TRIB	10336635	0.64	7106.5	39.01741	44.6	42	19	-0.54	80	0.90	107	1.55
GENERAL	10336645	7.44	7196.71	39.05185	48.4	783	223	-0.71	1126	0.44	721	-0.08
BLACKWOOD	10336660	11.2	7262.68	39.10741	54.8	1695	336	-0.80	2262	0.33	996	-0.41
WARD	10336674	4.96	7531.76	39.14074	67.6	995	149	-0.85	1468	0.48	493	-0.50
WARD	10336675	8.97	7341.47	39.13685	62.1	1788	269	-0.85	2382	0.33	828	-0.54
WARD	10336676	9.7	7288.91	39.13213	60.1	1859	291	-0.84	2437	0.31	892	-0.52
WOOD	10336693	1.69	8198.86	39.26130	41.6	38	51	0.33	101	1.66	186	3.88
GLENBROOK	10336730	4.11	7349.24	39.08741	26.6	57	123	1.16	121	1.13	440	6.71
LOGAN HOUSE	10336740	2.09	7816.76	39.06657	29.7	24	63	1.61	64	1.65	224	8.35
EDGEWOOD	10336756	0.81	7615.31	38.97546	28.3	9	24	1.70	24	1.66	109	11.11
EDGEWOOD	103367585	3.13	7529.35	38.96657	29.0	46	94	1.04	105	1.28	320	5.96
EAGLE ROCK	103367592	0.63	8286.26	38.95657	31.1	5	19	2.78	17	2.38	74	13.78
TROUT	10336770	7.4	8606.66	38.86324	42.4	152	222	0.46	392	1.58	449	1.95
TROUT	10336775	23.7	7820.54	38.90339	40.7	963	711	-0.26	1676	0.74	1399	0.45
TROUT	10336780	36.7	7931.58	38.91991	38.8	1238	1101	-0.11	2172	0.75	1923	0.55
					average			0.06		0.93		2.55
					max			2.78		2.38		13.78
					min			0.11		0.31		0.03

[1]Mean annual precipitation

(1) $\log_{10}(Q_{1\%})= 23.3825+ 1.1254\log_{10}(\text{area}) -6.886\log_{10}(\text{elevation}) + 3.0215\log_{10}(\text{MAP})$ (see Table 5.1)

(2) $Q_{1\%} = 30.0$ (area) (see Shively and Clyde, 2004)

(3) fraction difference = [(2)-(1)]/(1)

(4) $\log_{10}(Q_{1\%})= 13.1691+ 1.0121\log_{10}(\text{area}) -3.9758\log_{10}(\text{elevation}) + 2.5728\log_{10}(\text{MAP})$ (see Table 2.1, SPK 2005a)

(5) fraction difference = [(4)-(1)]/(1)

(6) $\log10(Q_{1\%}) = \log_{10}(7000) + 0.782\log_{10}(\text{area}) -2.18\log_{10}(\text{elevation}/1000) + 4.6 \log_{10}([\text{latitude}-28]/10)$ (Blakemoore, et al., 1997)

(7) fraction difference = [(6)-(1)]/(1)

l) Split sample testing

- Standard tests to examine the statistical significance of the GLS regression do not exist. Consequently, split sample testing was performed for a selected group of regional gages to test the predictive capability for regression equation predictions of peak flow quantiles.
- The regional gages were selected based on a minimum record length needed for the split sample test; and that the gages formed a reasonable region as measured by a statistical test of regression leverage (see technical appendix).
- The split sample tests found that the regression method applied in the study seems to produce consistent and accurate estimates of peak flow quantiles on the average. However, regression prediction error for an individual site prediction as measured by either the standard or average prediction error seems to be optimistic. Conclusions regarding the prediction accuracy at individual gages need to be tempered by the difficulty in estimating regression predictions at gages when gage records are relatively short, 10-20 years. Basically, a couple of gage estimates had a large effect in increasing

the estimated at-site prediction error. Generally, this caused the at-site prediction error to be greater than the regression standard or average prediction error.

m) Volume duration frequency analysis

- The volume duration frequency analysis was preformed to obtain regional relationships for the 1day, 3day, 7day, 10day, 15day and 30day annual maximum flow volumes. A standard Bulletin 17B analysis (IACWD, 1982) was performed to obtain quantile estimate for these volume duration frequency curves.
- These curves were developed to be consistent with the peak flow regression and across durations (i.e., estimated in a manner so that the curves for various durations do not intersect). To do this, peak flow and 1day annual maximum flow regressions, and regressions between the 1day and other durations were developed using ordinary least squares as shown in the following tables.
- The regression relations provide the average relationship between quantile (e.g., the 1% chance flow) for various durations, **the correlation shown is not an indication of prediction accuracy**. The average prediction error for the peak annual regression equations should be used to compute prediction confidence limits for the VDF curves. Example application of regression equations, including the computation of prediction confidence limits can be found in SPK (2005).

Lake Tahoe Basin regression relationships between peak annual quantile and 1 day annual maximum (based on log-Pearson III estimates from gage analysis, see Table 8.1)
(Regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50 or urban areas)

	0.99	0.95	0.9	0.8	0.5	0.2	0.1	0.04	0.02	0.01	0.002
b	0.958596	0.990323	0.97329	0.979087	0.988666	0.978598	0.972665	0.973848	0.974342	0.978921	0.979076
a	0.048461	-0.015	0.010924	-0.01762	-0.08182	-0.1054	-0.10293	-0.10213	-0.09836	-0.09954	-0.09004
correlation	0.997605	0.998376	0.996842	0.99676	0.995927	0.99353	0.990794	0.986736	0.984563	0.982225	0.980661

$\log_{10}(Q_{1day}) = \mathbf{a} + \mathbf{b}[\log_{10}(Q_{peak})]$, where Q_{1day} is the 1day duration quantile (e.g., 1day 0.01 exceedance probability flow (cfs/day)) and Q_{peak} is the quantile for the annual maximum peak flow (cfs)

Lake Tahoe Basin regression relationships between 1day quantile and other duration quantiles (based on log-Pearson III estimates from gage analysis, see Table 8.2)
(Regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50 or urban areas)

[1]probability	[2]constants/correlation	3day	7day	10day	15day	30day
0.99	B	0.993308	0.99025	0.982075	0.96804	0.944451
	A	-0.01257	-0.03303	-0.04046	-0.05078	-0.07836
	Correlation	1.000	0.998	0.998	0.997	0.995
0.95	B	0.985982	0.971634	0.962417	0.951393	0.934651
	A	-0.00648	-0.01888	-0.02567	-0.04312	-0.08261
	Correlation	1.000	0.998	0.998	0.998	0.997
0.90	B	0.99923	0.987621	0.983363	0.975626	0.961631
	A	-0.03614	-0.06279	-0.07952	-0.10316	-0.14471
	Correlation	0.999	0.998	0.998	0.998	0.997
0.80	B	0.996301	0.98171	0.973487	0.982671	0.968724
	A	-0.03775	-0.06061	-0.06864	-0.12775	-0.1647
	Correlation	0.999	0.999	0.998	0.998	0.998
0.50	B	0.998265	0.987621	0.981524	0.978761	0.965912
	A	-0.05056	-0.08833	-0.10181	-0.13463	-0.16694
	Correlation	1.000	0.999	0.999	0.998	0.998
0.20	B	0.99221	0.975531	0.970496	0.963261	0.950199
	A	-0.04933	-0.07828	-0.09573	-0.11602	-0.14453
	Correlation	1.000	0.998	0.998	0.997	0.996
0.10	B	0.983585	0.958233	0.950237	0.939259	0.924215
	A	-0.03924	-0.05574	-0.06823	-0.07869	-0.10142
	Correlation	0.999	0.997	0.996	0.995	0.994
0.04	B	0.970159	0.926978	0.911073	0.894943	0.875257
	A	-0.01914	-0.00588	-0.00369	-0.00217	-0.01318
	Correlation	0.999	0.995	0.993	0.990	0.988
0.02	B	0.966892	0.906824	0.886033	0.86466	0.841265
	A	-0.012	0.029517	0.04166	0.055717	0.052658
	Correlation	0.998	0.992	0.989	0.986	0.982
0.01	B	0.962746	0.884046	0.854176	0.831611	0.803941
	A	-0.00672	0.070869	0.106669	0.122217	0.128375
	Correlation	0.998	0.994	0.999	0.999	0.999
0.002	B	0.976006	0.859373	0.819634	0.783623	0.744137
	A	-0.03389	0.118144	0.170341	0.221591	0.261264
	Correlation	0.997	0.986	0.978	0.967	0.958

[1]Exceedance probability
[2]$\log_{10}(Q_{nday}) = \mathbf{a} + \mathbf{b}[\log_{10}(Q_{1day})]$, where Q_{nday} is the duration quantile (e.g., 3day 0.01 exceedance probability, cfs./day)) and Q_{1day} is the quantile for the 1day duration volume duration frequency curve (cfs/day)

n) Low-flow frequency analysis

- The low-frequency analysis focused on 7day duration curve because of the importance of the 7day 10year low flow in regulatory applications related to water quality.
- Analysis of the regional gages was not possible since records for most of these gages were highly affected by water supply diversions.
- A sufficient number of Lake Tahoe Basin gages unaffected by water supply diversion were identified for the purposes of developing regression equations.
- A log-Pearson III distribution estimated using the standard method of moments (see IACWD, 1982) provided a reasonable fit to the annual minimum 7day low-flows obtained from gage data.
- Ordinary least squares was used to develop the low-flow frequency curves given limitations on the scope of the study. Error measures provided for the regression will be only approximate given that the regression residual error distribution will not correspond to the ideal estimation requirements of ordinary least squares.
- The regression relations is given in the following table. The best regressions as judged by the standard error included annual mean snowfall, mean annual temperature and drainage area. Including snowfall in the regression improves the prediction error; but not significantly for the critical- less frequent non-exceedance probabilities such as the 0.10 (the 7day 10-year low flow). The recommended regressions result in more consistent frequency curves near the extreme of the range of regression equation applicability.

7day low flow regional regression relationship[1] 9 (see Table 9.4)
(Regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50 or urban areas)

[2]Probability	b_0	[3]area (b_1)	[4]snowfall (b_2)	[5]temperature (b_3)	[6]R^2	[7]SE
Recommended regression						
0.01	133.84415	0.68033		-83.20121	0.77	0.46
0.05	107.53622	0.58155		-66.80492	0.80	0.35
0.10	106.50728	0.57185		-66.10442	0.82	0.32
0.20	97.14648	0.54907		-60.24327	0.87	0.27
0.50	74.74878	0.50574		-46.26403	0.86	0.23
0.80	57.96734	0.47266		-35.75592	0.78	0.25
0.90	50.49741	0.45584		-31.06690	0.71	0.27
Best regression						
0.20	111.07000	0.68248	-0.86005	-67.65282	0.86	0.26
0.50	92.88154	0.67949	-1.12005	-55.91357	0.90	0.18
0.80	80.95735	0.69295	-1.42008	-47.99028	0.89	0.16
0.90	76.48834	0.70488	-1.60545	-44.89824	0.88	0.16

[1]$\log_{10}(Q_p) = b_0 + b_1(\log_{10}(\text{area})) + b_2(\log_{10}(\text{snowfall})) + b_3(\log_{10}(\text{temperature}))$, Q_p is the flow (cfs) for cumulative (non-exceedance probability), see SPK (2005) for example application
[2]cumalive probability (non-exceedance), e.g., 0.10 is the 10year return interval for the 7day low flow
[3]regression coefficient for area (square miles)

[4]regression coefficient for watershed average mean annual snowfall (inches)
[5]regression coefficient for watershed average mean annual temperature (^oF)
[6]adjusted multiple coefficient of determination (log units)
[7]standard error (log-unit)

- Some concern existed that the limited number of gages, and the gap in drainage area available for these gages biased the regression estimates. Sensitivity analysis and estimates of the leverage statistic indicated that no bias was prevalent.

n) Flow-duration regressions
- The same Lake Tahoe basin gages used in the low-flow frequency analysis were used in the flow duration analysis because these gages are unaffected by water supply diversions.
- Flow-duration curves are generally very non-linear, precluding these curves description by some simple analytic distribution. Consequently, regression equations were developed for interpolated flow-duration quantiles. The interpolated flow-duration quantiles were obtained by fitting cubic splines to the frequencies derived from gage data.
- As in the case of low-flow frequency curves, ordinary least squares were used to develop the flow-duration curves. Error measures provided for the regression will be only approximate given that the residual distribution will not correspond to the ideal estimation requirements of ordinary least squares.
- The regression equations were developed for flow-duration curves are shown in the following table.
- The recommended regression for the 50% exceedance (or equivalently the fraction exceeded 5)5 of the time) uses mean annual precipitation (MAP) rather than mean annual temperature (MAT), even though the regression with MAT gives a slight improvement in accuracy. Using MAP results in more consistent predictions for applications at the extreme of the regression range of applicability.

Lake Tahoe watersheds daily flow duration regression relationship parameters[6] (see Table 10.2) *(Regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50 or urban areas)*

[5]Frequency exceeded (f)	b_0	[1]area (b_1)	[2]elevation (b_2)	[3]MAT (b_3)	[4]MAP (b_4)
99%	-43.8641	0.927195	11.04962		
95%	-38.8409	0.945971	9.789445		
90%	-32.7125	0.970529	8.235106		
50%	32.85813	0.80133		-20.24583805	
[7]50%	-1.64067	0.89692			0.942848
10%	-4.21429	0.85337			3.011556
5%	-4.11273	0.889998			3.038292
1%	-3.97303	0.965017			3.042417

[1]drainage area (square miles)
[2]mean basin elevation (feet msl)
[3] watershed average mean annual temperature (^oF)

[4]watershed average mean annual precipitation
[5]annual frequency daily flow level (cfs/day) exceeded
[6]Flow duration curve regression, $\log_{10}(Q_f) = b_0 + b_1\log_{10}(\text{area})\ b_2\log_{10}(\text{elevation}) + b_3\log_{10}(\text{MAT}) + b_4\log_{10}(\text{MAP})$
[7]Recommend regression for 50% frequency exceeded flow although slightly better R^2 using MAT rather than MAP

Lake Tahoe watersheds daily flow duration regression goodness of fit and prediction error (see Table 10.3)

[1]Frequency exceeded	[2]Adjusted R^2	[3] standard error
99%	0.86	0.18
95%	0.87	0.18
90%	0.90	0.15
50%	0.91	0.15
	[4]0.87	0.18
10%	0.96	0.13
5%	0.96	0.13
1%	0.95	0.15

[1] annual frequency daily flow level (cfs/day) exceeded
[2]log regression multiple coefficient of determination (adjusted for degrees of freedom)
[3] standard error $\log_{10}$ units
[4]Recommend regression for 50% frequency exceeded flow although slightly better R^2 using MAT rather than MAP

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1. Introduction

1.1. Purpose

The purpose of this report is to describe the regional analysis study performed to develop regional regression equations for estimating:

- annual flow-duration curves
- annual peak flow frequency and maximum volume duration frequency curves
- annual 7day low-flow frequency curves

in the Lake Tahoe Basin (see figure 1.1).

Regional regression equations typically take the following general form:

$$\log_{10}\left(Q_p\right) = b_0 + b_1\log_{10}\left(X_1\right) + b_2\log_{10}\left(X_2\right) + \ldots e \qquad (1.1)$$

where Q_p is the flow quantile of interest (e.g., the 1% chance annual peak flow), the X_i are independent parameters obtained from meteorologic and watershed characteristics (e.g., mean annual precipitation, drainage area), b_0 is the regression constant and the b_i are coefficients to be determined from the regression with observed data, for i=1,2 …n, where n is the number of parameters, and e is residual error describing the inability of the regression to explain the variation of $Q_{p.}$ The coefficients shown in equation (1.1) are obtained from applying a least regression algorithm using estimates of Q_p obtained from a frequency analysis of stream gage flow records, and data for gage watershed characteristics, the X_i. (for a more detailed discussion of the application of least squares estimation see section 11, technical appendix).

The regional regressions were developed to address traditional drainage and best management practice design problems, provide measures of stream flow characteristics for restoration design and estimates of critical low-flow periods for meeting regulatory water quality requirements. The regression equations for annual peak flow and maximum volume duration frequency curves will be used to compute design flows (e.g., the 1% chance exceedance flow) in natural ungaged watersheds. The frequency curves can be used to obtain design peaks and volumes for sizing culvert and retention facilities. Additionally, the frequency curves can be used to evaluate/validate/calibrate watershed model applications to these ungaged watersheds. The regression equation estimates of low-flow and flow-duration frequency curves can be used to validate and verify continuous simulation watershed models that potentially can be used to estimate design water quality volumes for best management practice. The regression equation flow-duration curve estimates are potentially useful for defining the stream flow inundation levels important to locating vegetation in stream restoration efforts. The low-flow regression frequency curves can be used to estimate the 7day-10year low flow important to addressing stream flow water quality regulatory requirements. For a further discussion of the regression equation application see SPK, 2005.

The derivation of the regional equations depends on resolving two fundamental competing requirements: 1) pool records from as many gages as possible to have as long an effective stream flow record length as possible; and, 2) limit the gages to a homogenous hydrologic-meteorologic region where a statistically significant relationship can be established between flow quantiles and watershed meteorology and physical characteristics. Pooling records to increase record length is important because it reduces statistical sampling error in flow quantile estimates. Ideally, pooling records increases record length when the flow records from gages with very similar runoff characteristics can be combined. For example, 10 gages with 100 years of record length could be pooled in analysis to obtain an effective record length of 10*100=1000 years. Unfortunately, watershed runoff characteristics differ in some respect and flow values are spatially correlated reducing the effective record length. The difference in runoff characteristics and correlation between flow values of the runoff process requires that the region of consideration be limited, reducing the number of gages, so that a statistically significant predictive equation can be found.

Section 2 describes the selection of the region and data base of both watershed meteorologic and physical characteristics, and, the gage flow records in this region used to develop the regression equations. Regression equations will be developed for annual peak and volume duration flow, 7day low-flow, and flow-duration frequency curves. Section 3 provides a basic description of each of these flow frequency curves. Frequency analysis estimates of these curves from stream gage data provide estimates of Q_p used to estimate regression coefficients in equation (1.1). Section 4 describes the comparison of a scaling method and the regression approach to obtaining regional relationship. As a result of the comparison, the regression approach was selected as most appropriate for developing the regional relationship. Section 5-10 provides regression analysis results. A technical appendix is provided in section 11 which describes the mathematical and statistical methods used to develop the regional regression equations, as well as the software used to apply the methods. Section 12 provides tables of the basic data used to develop the regressions.

1.2. Application of results

The regression equations were developed for natural/open drainage areas > 0.5 square miles, basins where a significant portion of drainage area exceeds 7000 ft msl, and should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50 or urban areas. This minimum drainage area limits the direct application of these equations to traditional drainage and best management practice design which usually focus on much smaller drainage areas. However, the equations will be very valuable for comparison to, calibration or verification of watershed model simulations used to predict flow-frequency in ungaged areas. For example, design runoff, such as the 1% annual maximum flow, computed using the Soil Conservation Service Curve Numbers can be verified in comparison with regression equation predictions. Consequently, the regression equation will prove useful for relatively large drainage area computations and for calibration of ungaged watershed model parameters.

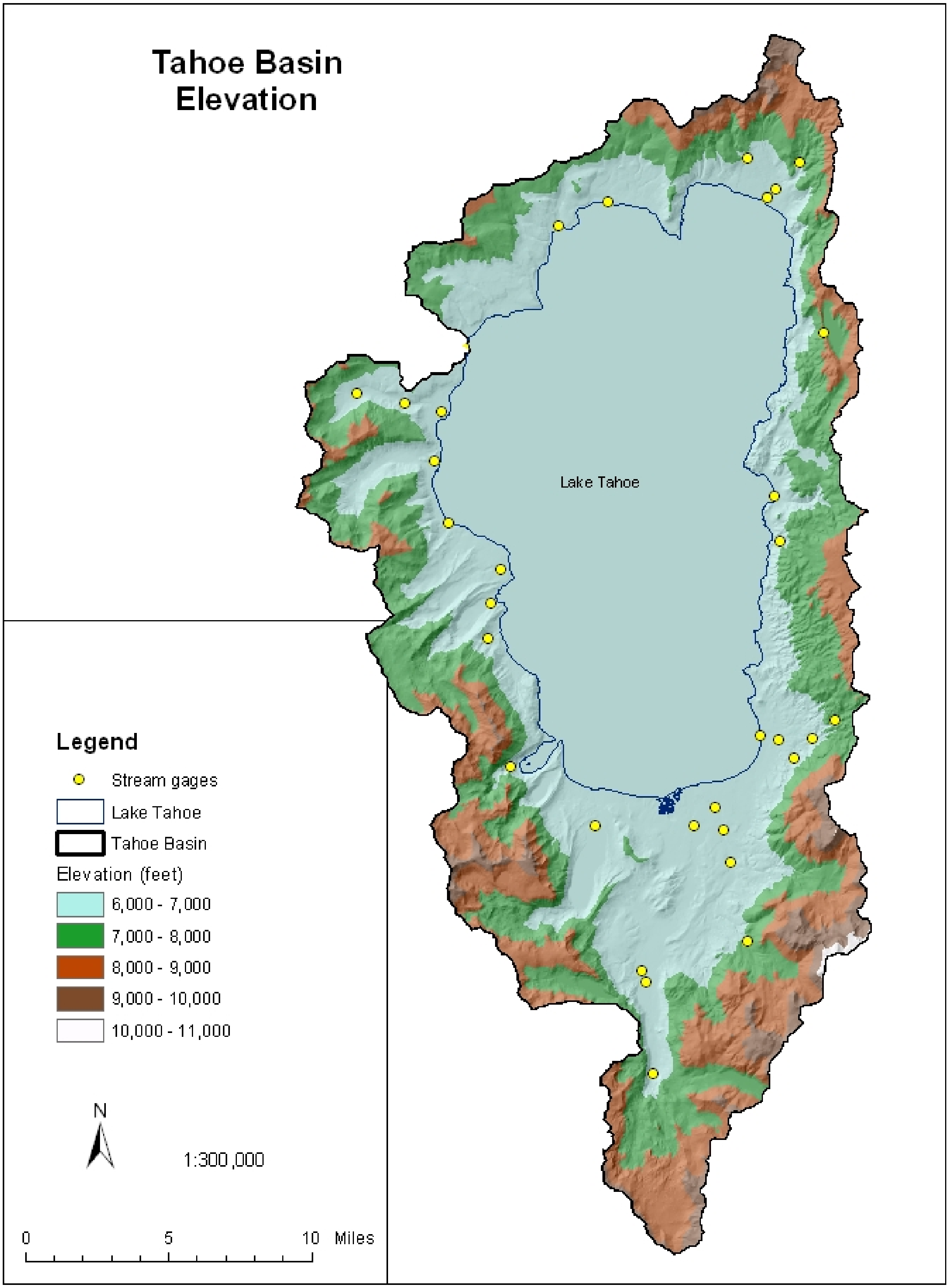

Figure 1.1: Lake Tahoe Basin Elevation

2. Regional watershed meteorologic and physical characteristics

2.1. Watershed and meteorologic characteristics

The initial problem in developing regional regression equations is to determine the region of interest (the geographic boundary) and the independent parameters for watersheds in the region(the X_i in equation (1.1)) to use in the regression. The initial step in selecting the region is to identify watershed which have similar flow-frequency characteristics. The initial region can be refined based on the statistical tests performed with the regression analysis.

The purpose of this section is to provide the background information on the watershed and meteorologic characteristics that will be useful in identifying the initial region for developing regression equations. The region, initially, will look to encompass areas, including the Lake Tahoe Basin, that have similar precipitation-runoff characteristics. This will maximize the number of gages and effective flow record that can be used in developing the regression equations. Subsequent regression analysis will examine if the gage information from outside the basin improves the predictive capability of the regressions.

The watershed and meteorologic characteristics of the Lake Tahoe Basin are described by others (e.g., Jeton, 1999 and Crippen and Pavelka, 1970). Understanding these characteristics is important both for delineating boundaries and developing parameters for the regionalization studies.

The basin has the following meteorologic characteristics (see, Jeton, 1999):

- Mean monthly temperatures at Tahoe City (altitude 6,230 ft) recorded by the National Weather Service range from a minimum of 17^{o}F for January to a maximum of 77^{o}F for July;
- Precipitation amounts vary from 15 inches to 80 inches annually with most occurring from November-March as snow or a mixture of snow and rain;
- Snowmelt generates more than 80% of the annual runoff.

Understanding the orographic influence on precipitation and temperature is important to delineating boundaries and aggregating stream gages for a regional analysis. An important question is whether or not there are significant micro-climates within the Lake Tahoe Watersheds caused by the orographic impacts than would be different than is experienced for other watersheds north and south of the basin? Presumably, the Lake Tahoe basins will experience similar meteorologic influences as other watersheds immediately to the east of the Sierra Mountain Ridge. The general trend being decreasing precipitation and lower annual runoff per square mile the further east the watershed.

Jeton (pg. 15, 1999) examined precipitation trends within the basin and made the following observations:

> *Mean monthly precipitation series form 19 climatic sites (table 2) in the Tahoe and Truckee River Basins were plotted against altitude to estimate mean regional precipitation lapse rates. ... No strong, consistent precipitation-altitude relations were evident on a regional scale amidst the scatter of points, especially during the winter months when most of the annual precipitation falls. Influence of east-west rain shadow appear to affect the sites about the same as altitude relations. For example, Boca(5,580 ft, fig 1A) receives on average 50 percent less precipitation than Donner Memorial State Park (5,940 ft) during January and February. The Boca site is sufficiently east of the Sierra Nevada crestline to be influenced by the rain-shadow effect that results in decreased precipitation. ......*

Jeton (pg. 16) further states:

> *The second part of the precipitation data analysis looked at the spatial variability to determine whether variations about the local mean formed predictable patterns. This was accomplished using a cluster analysis based on a rotated empirical-orthogonal-function (EOF) analysis. ....The EOF analysis indicates that, on a regional scale, no natural clusters or precipitation variation exist in the Tahoe-Truckee Basin. These basin are evidently small enough so that precipitation variations are either shared or effectively random, at monthly time scales. ....*

Apparently, no micro-climates affecting precipitation could be detected based on an analysis of monthly precipitation data.

Jeton (pg. 17) also estimated lapse rates for the basin to investigate orographic influences on temperature:

> *While additional higher altitude sites are needed to remove some of the uncertainty, these regional comparisons suggest that, during the coldest months for the Lake Tahoe Basin no strong temperature lapse rate is evident. between the ridgeline and lake level. .... However model runs made without a temperature lapse rate typically resulted in under-simulation of spring snow-melt, and excessive basin runoff. This suggests that on a subbasin scale, as represented in this study, temperature adjustments to account for altitude differences are necessary to adequately simulate runoff. .....*

Apparently, the temperature gage network was not sufficient to detect the variation of temperature that is consistent with simulating snowmelt processes within the basin. The important conclusion to be drawn from these findings are that if temperature and precipitation are to be used as a regional parameter than some method must be found to reasonably map temperature variation to reflect stream flow variation.

The variation of meteorologic characteristics were investigated by using PRISM together with GIS software to both add to the finding of Jeton's and provide information for the regional regression study. Figures 2.1-2.3 display the variation of mean annual precipitation, mean annual temperature, and mean annual total snowfall for the Lake Tahoe Basin. Precipitation depth-duration-frequency characteristics, such as the 1% chance 2-hour precipitation, were also developed from NOAA14. However, mean annual precipitation was as valuable as these precipitation frequency characteristics in explaining the variation of flow-frequency statistics in preliminary regression studies. Consequently, this data was not used in the final regression investigations

Watershed characteristics are obviously important to consider in selecting parameters to describe stream flow. Drainage area and mean basin elevation were considered given the values of these parameters in previous regression studies covering the study area (see, Blakemoore, et al. 1997).

Jeton (pg 5.) notes that glaciation has removed more of the permeable soil cover in the western basin than the eastern portion of the basin. Consequently, the runoff efficiency (stream flow as a function of precipitation) is greater for western slope than eastern slope streams.

Basin fill important for ground water storage is most prevalent in the basin's two major aquifers at South Lake Tahoe and Incline Village. Lesser amounts of unconsolidated fill can be found in stream alluviums. The variation in surficial geology, where soils vary from near surface bedrock in the south-western portion of the basin to deep unconsolidated fill in the south-western portion would be expected to cause a great deal of variation in stream low-flow characteristics.

However, relating surficial geology characteristics (the only readily available measure of subsurface characteristics) to low-flow characteristics (e.g., see Kroll et al., 2004) has not been very successful. A useful regression for low-flow and flow-duration frequency characteristics will most likely depend on both finding periods of record unaffected by diversion; and, selecting an appropriate combination of watershed surface characteristics (e.g., drainage area) and meteorologic characteristics.

The watershed characteristics an meteorology of the Lake Tahoe Basin indicates that the following strategy should be employed in developing regional parameters to explain stream flow variation:

- Watershed physical characteristics such as drainage area and elevation . are obvious choices to consider; and, were used effectively in previous studied (see Blakemoore et al., 1997);
- Meteorologic variables related to precipitation and temperature are likely important to explaining certain aspects of stream flow, such as peak flow frequency and flow duration;
- The trend of decreasing precipitation and stream flow from west to east necessitates consideration of a parameter that relates to a watershed longitude (e.g., mean annual precipitation or longitude itself);
- Finding successful region relationships for low-flow characteristics will depend on finding stream flow records that are not unduly influence by diversions.

Estimating these parameters will be simplified by the use of GIS technology. PRISM software (Taylor, et al., 1993) applications with GIS will be used to estimate the spatial variation of estimating precipitation, temperature and other meteorologic variables for the sub-watersheds draining to the stream gages of interest in this study.

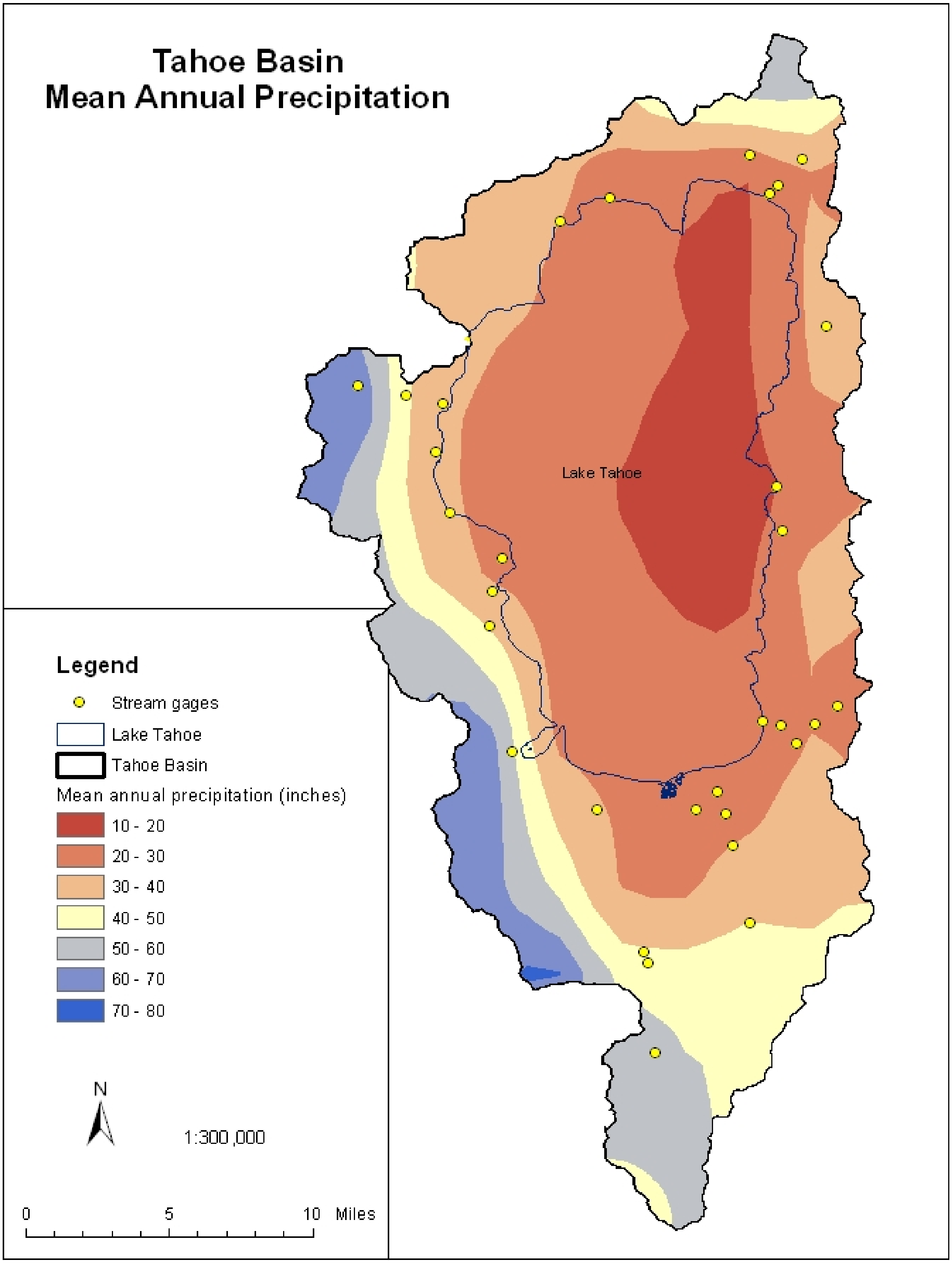

Figure 2.1: Mean annual precipitation (inches) (see Daly et al., 2004)

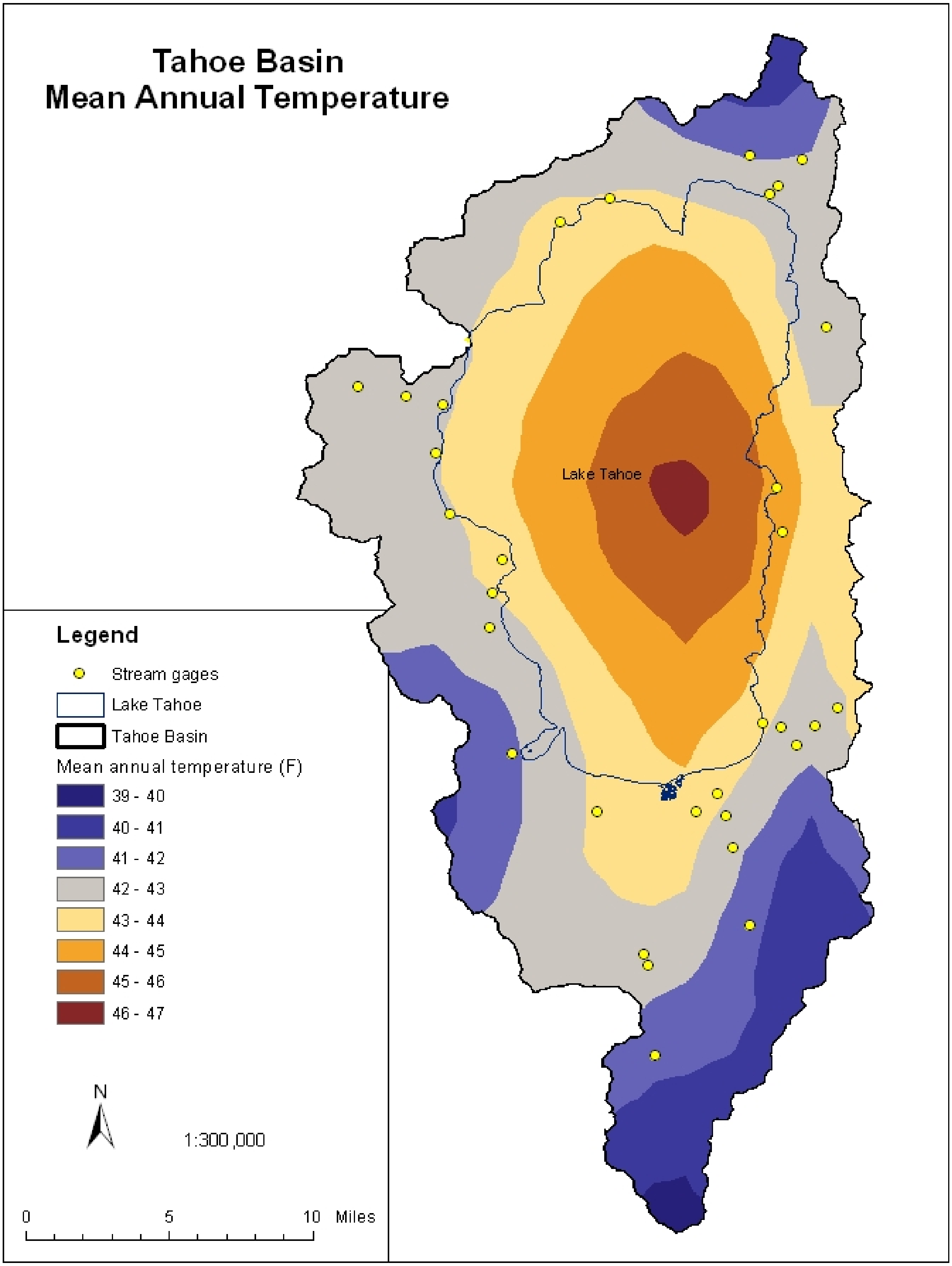

Figure: 2.2: Mean annual temperature (^oF) (see Daly et al., 2004)

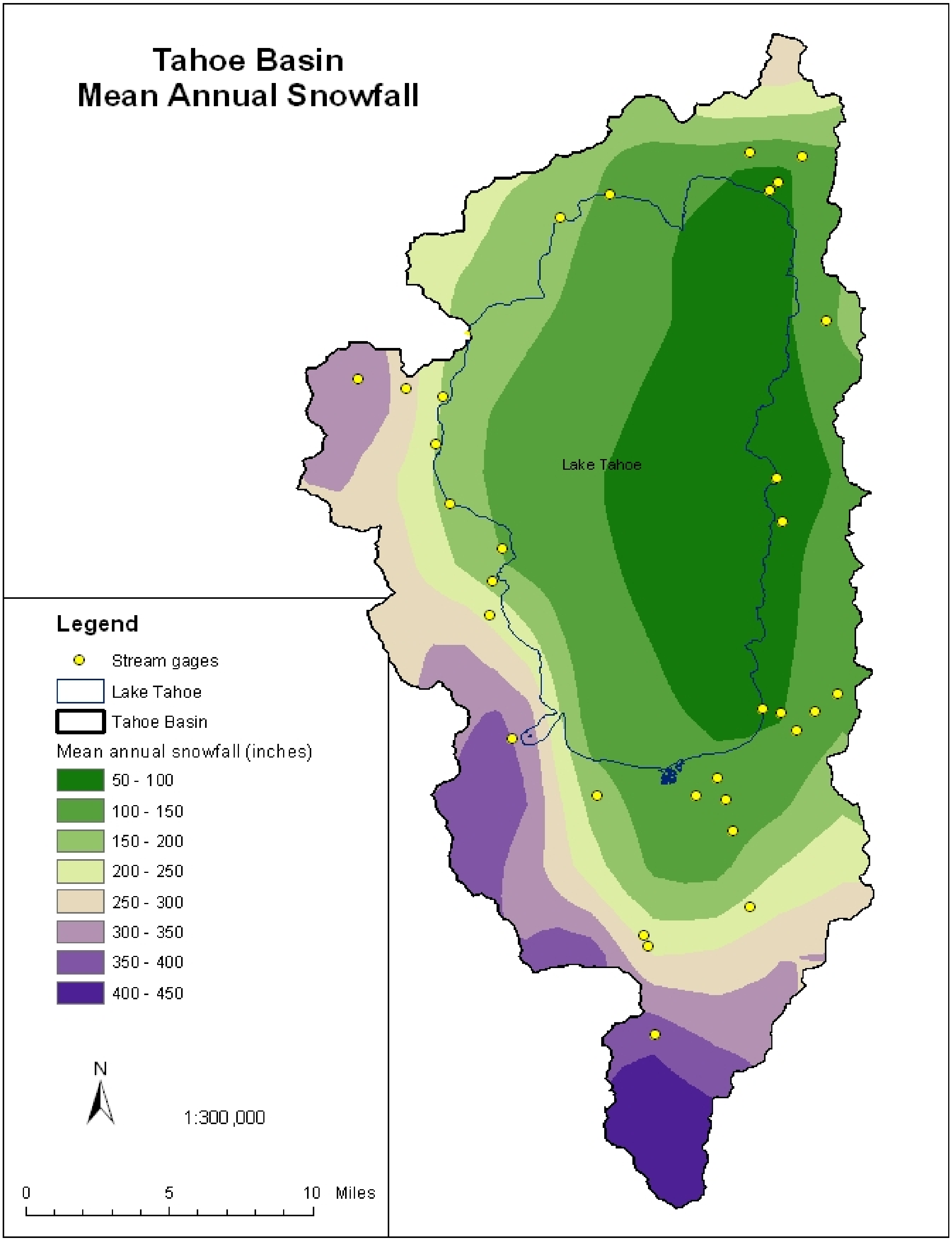

Figure 2.3: Mean total annual snowfall (inches), (see Daly et al., 2004)

2.2. Gage data base

Stream flow records were collected for US Geological Survey gages within the Lake Tahoe Basin and an extended region with similar topographic and meteorologic characteristics in the Sierra Nevada mountains. The regional gages were identified as being useful for regional regression development in a previous flood-frequency study for the southwestern United States (see Blakemore, et al., 1997).

Both annual peak flow and daily average flow is available for these gages. The peak flow data contains annual maximum flow in cubic feet per second (cfs) for each water year (October through September), with corresponding data flags regarding historic information, regulation, backwater, etc. The daily flow data contains continuous records of average daily flow for a period of record, with data flags indicating the quality of the data. A description of each gage, including factors affecting the homogeneity of the record such as regulation and diversions, was obtained from the U.S. Geological Survey Water Supply Paper 2127 (1974).

The peak flow data was used to estimate the annual peak flow frequency frequencies curves. Table 2.1 and 2.2 provide a description (latitude, longitude, drainage area) of both regional and Lake Tahoe Basing gages potentially useful in the study. Information on the peak flow and daily gages is presented separately in the following tables because various factors affect the usefulness depending on the data application. In the case of peak flows, reservoir regulation which potentially can reduce peak flows is particularly important to assessing the value of the data in estimating peak and volume duration frequency curves. A flag indicating significant regulation would exclude this gage from the analysis of the frequency curves. Not only regulation, but also diversions are important to assessing the usefulness of gages for low-flow and flow-duration analysis. A significant problem in using daily flow records, particularly in the arid western U.S., is the non-homogeneity of the period of record because of diversions for water supply or hydro-power.

Tables 2.3-2.5 describe the period of record, data quality flags, and effects or regulation on the peak flow period of record for the regional gages. Gages were excluded from the analysis because of either significant regulation or limited period of record. Note that Bulletin 17B, the federal guidelines for performing flood frequency analysis, recommend a minimum of 10-years of data be available for estimating a flood-frequency curve. Consequently, gages with less than 10-years of data were excluded from the analysis.

Tables 2.6-2.7 provide the same information for Lake Tahoe Basin gages (information on data flags and regulation comments were combined into one table because regulation is not as prevalent for Lake Tahoe as within the entire region considered).

Daily stream flow information for regional gages is provided in tables 2.8-2.9. Although there is a significant period of record available, the non-homogeneity of the records due to diversions makes these gages unusable for a regional low-flow or flow-duration regression study.

A sufficient number of Lake Tahoe Basin gages had period of records unaffected by diversions (personal communication, Rita Whitney, 2004) where low-flow and flow-duration analysis could be performed. Tables 2.10 and 2.11 provide the information on period of record and diversions/regulation within the Lake Tahoe Basin.

Table 2.1: Regional gages, latitude, longitude, drainage area (see Blakemore et al., 1997), peak and daily stream flow records

USGS ID	gage name	[1]latitude	[1]longitude	[2]area
10265200	Convict Creek near Mammoth Lakes, CA	37.6071561	118.8487408	18.2
10265700	Rock Creek at Little Round Valley near Bishop, CA	37.5540986	118.6851253	35.8
10267000	Pine Creek at Division Box near Bishop, CA	37.4163208	118.6217864	36.4
10268700	Silver Canyon CREEK near Laws, CA	37.4077061	118.2795494	20
10276000	Big Pine Creek near Big Pine, CA	37.1449311	118.3153797	39
10281800	Independence Creek below Pinyon Creek near Independence, CA	36.7785439	118.2645410	18.1
10286000	Cottonwood Creek near Olancha, CA	36.4388247	118.0809189	40.1
10287210	Bridgeport Creek near Bodie, CA	38.0790889	119.0454236	13.1
10289000	Virginia Creek near Bridgeport, CA	38.1915869	119.2093200	63.6
10291500	Buckeye Creek nr Bridgeport, CA	38.2388078	119.3259922	44.1
10292000	Swauger C nr Bridgeport, CA	38.2832519	119.2996022	52.8
10293000	E Walker River near Bridgeport, CA	38.3276958	119.2148758	359
10295200	W Walker River at Leavitt Meadows near Coleville, CA	38.3304697	119.5523914	73.4
10295500	Lower Walker River near Bridgeport, CA	38.3607483	119.4448869	63.1
10296000	W Walker River below Lower Walker River Near Coleville, CA	38.3796367	119.4501650	181
10296500	W Walker River near Coleville, CA	38.5132450	119.4498872	250
10296800	Slinkard Creek tributary Near Topaz, CA	38.6471306	119.5621136	0.25
10299100	Desert Creek near Wellington, NV	38.6485236	119.3259925	50.4
10302010	Reese River Canyon near Schurz, NV	38.8499194	118.7829208	14
10304500	Silver Creek below Pen Creek near Markleeville, CA	38.5999072	119.7760108	19.6
10306000	Hot Springs Creek near Markleeville, CA	38.6999061	119.8510122	14.4
10308100	Millberry Creek at Markleeville, CA	38.6999056	119.7843436	5.1
10308200	E Fork Carson River below Markleeville Creek near Markleeville, CA	38.7146275	119.7648983	276
10308800	Bryant Creek near Gardnerville, NV	38.7937950	119.6726730	31.5
10309000	East Fork Carson River near Gardnerville, NV	38.8449064	119.7046189	356
10310000	West Fork Carson River at Woodfords, CA	38.7696278	-119.8337892	65.4
10310400	Daggett Creek near Genoa, NV	38.9651853	119.8496236	3.82
10310500	Clear Creek near Carson City, NV	39.1132422	119.7982364	15.5
10311000	Carson River near Carson City, NV	39.1076875	119.7132333	886
10311100	Kings Canyon Creek near Carson City, NV	39.1537981	119.8079597	4.06
10311200	Ash Canyon Creek near Carson City, NV	39.1762981	119.8057380	5.2
10311450	Brunswick Canyon near New Empire, NV	39.1721331	119.6871222	12.7
10339400	Martis Creek near Truckee, CA	39.3287958	120.1176964	39.9
10340500	Prosser Creek below Prosser Creek Dam near Truckee, CA	39.3732403	120.1315869	52.9
10342000	Little Truckee River near Hobart Mills, CA	39.5012939	120.2774264	36.5
10343500	Sagehen Creek near Truckee, CA	39.4315725	120.2379792	10.5
10348900	Galena Creek near Steamboat, NV	39.3618544	119.8279658	8.5
10350100	Long Valley Creek near Happy Valley, NV	39.4818569	119.6204603	82.6

[1]Decimal degrees

[2]Drainage area in square miles

Table 2.2: Lake Tahoe Basin Stream Gages, latitude, longitude and drainage area, peak and daily stream flow records

USGS ID	Description	[1]latitude	[1]longitude	[2]area
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	38.7962961	-120.0190719	14.09
10336600	Upper Truckee River near Meyers, CA	38.84296306	-120.02462750	33.1
103366092	Upper Truckee River at Highway 50 above Meyers, CA	38.8485186	-120.0271275	34.28
10336610	Upper Truckee River at South Lake Tahoe, CA	38.92240778	-119.9915706	54.9
10336626	Taylor Creek near Camp Richardson, CA	38.92157444	-120.0612953	16.7
10336630	Eagle Creek near Camp Richardson, CA	38.95129667	-120.1115747	6.38
10336635	Lake Tahoe Tributary Near Meeks Bay, CA	39.0174078	120.1265756	0.64
10336640	Meeks Creek at Meeks Bay, CA	39.0357408	-120.1257428	8.08
10336645	General Creek near Meeks Bay, CA	39.05185194	-120.1185208	7.44
10336650	Quail Lake Creek at Homewood Bay, CA	39.0760183	-120.1526894	0.95
10336658	Madden Creek at Homewood, CA	39.09074056	-120.1626903	2.06
10336660	Blackwood Creek near Tahoe City, CA	39.1074072	-120.1621353	11.2
10336674	Ward Creek below Confluence near Tahoe City, CA	39.14074	-120.2121378	4.96
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	39.13685139	-120.1810256	8.97
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	39.13212917	-120.1576914	9.7
10336693	Wood Creek near Crystal Bay, NV	39.2612964	119.9574117	1.69
10336686	[3]Carnelian Creek at Carnelian Bay, CA	39.22685110	-120.08158080	
10336689	Snow Creek at Tahoe Vista, CA	39.23824028	-120.0396356	4.43
10336698	Third Creek near Crystal Bay, NV	39.2404633	-119.9465775	6.02
103366993	Incline Creek above Tyrol Village near Incline Village, NV	39.25879694	-119.9232439	2.85
103366995	Incline Creek at Hwy 28 at Incline Village, NV	39.2454633	-119.9390772	4.54
10336700	Incline Creek near Crystal Bay, NV	39.24018556	-119.9449106	6.69
10336715	Marlette Creek near Carson City, NV	39.17213056	-119.907963	2.86
10336730	Glenbrook Creek at Glenbrook, NV	39.08740806	-119.9399056	4.11
10336740	Logan House Creek nr Glenbrook, NV	39.0665747	-119.9354606	2.09
[3]10336756	Edgewood Creek Tributary near Daggett Pass. NV	38.9754633	-119.9010133	0.81
10336758	Edgewood Creek Tributary at Highland Tributary near Tahoe Village, NV	38.97268556	-119.9093469	3.18
103367585	Edgewood Creek at Palisade Drive nearr Kingsbury, NV	38.96657444	-119.9160136	3.13
103367592	Eagle Rock Creek nr Stateline, NV	38.95657444	-119.9276806	0.63
10336760	Edgewood Creek at Stateline, NV	38.96601917	-119.937125	5.61
10336765	Edgewood Creek at Lake Tahoe near Stateline, NV	38.9679636	-119.9493475	5.5
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	38.86324056	-119.95823670	7.4
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	38.90339444	-119.9688917	23.7
10336780	Trout Creek near Tahoe Valley, CA	38.91990778	-119.9724036	36.7
10336785	Heavenly Valley Creek near Tahoe Valley, CA	38.92129667	-119.9712925	3.1
10336790	Trout Creek at South Lake Tahoe, CA	38.93213	-119.9787925	40.4

[1]Decimal degrees

[2]Drainage area in square miles, [3]Drainage area not reported by USGS estimated using GIS software

Table 2.3: Regional gages annual peak discharges period of record, period of record

USGS ID	gage name	begin	end	years
10265200	Convict Creek near Mammoth Lakes, CA	5/21/1926	7/16/1978	53
10265700	Rock Creek at Little Round Valley near Bishop, CA	6/14/1927	6/9/1978	52
10267000	Pine Creek at Division Box near Bishop, CA	6/26/1922	5/27/1979	58
10268700	Silver Canyon CREEK near Laws, CA	4/14/1930	6/22/1978	49
10276000	Big Pine Creek near Big Pine, CA	7/15/1908	9/5/1978	62
10281800	Independence Creek below Pinyon Creek near Independence, CA	7/3/1923	7/27/1978	56
10286000	Cottonwood Creek near Olancha, CA	6/13/1906	9/10/1976	68
10287210	Bridgeport Creek near Bodie, CA	1/31/1963	1973-04-00	11
10289000	Virginia Creek near Bridgeport, CA	4/14/1954	5/14/1975	22
10291500	Buckeye Creek nr Bridgeport, CA	5/20/1954	5/25/2001	32
10292000	Swauger C nr Bridgeport, CA	3/9/1954	5/14/1975	22
10293000	E Walker River near Bridgeport, CA	5/22/1923	5/12/2001	79
10295200	W Walker River at Leavitt Meadows near Coleville, CA	5/20/1946	5/17/1970	23
10295500	Lower Walker River near Bridgeport, CA	2/2/1945	5/16/2001	48
10296000	W Walker River below Lower Walker River Near Coleville, CA	12/11/1937	5/16/2001	64
10296500	W Walker River near Coleville, CA	6/1/1903	5/17/2001	76
10296800	Slinkard Creek tributary Near Topaz, CA	1/31/1963	1973-00-00	11
10299100	Desert Creek near Wellington, NV	8/17/1965	5/23/2000	18
10302010	[2]Reese River Canyon near Schurz, NV	1963[1]	6/28/1991	22
10304500	Silver Creek below Pen Creek near Markleeville, CA	5/2/1947	7/31/1973	27
10306000	Hot Springs Creek near Markleeville, CA	5/2/1947	6/1/1957	11
10308100	Millberry Creek at Markleeville, CA	1/31/1963	04/1973	10
10308200	E Fork Carson River below Markleeville Creek near Markleeville, CA	1/2/1997	5/12/2001	5
10308800	Bryant Creek near Gardnerville, NV	8/7/1961	4/22/2001	23
10309000	East Fork Carson River near Gardnerville, NV	5/28/1890	5/12/2001	82
10310000	West Fork Carson River at Woodfords, CA	1890[1]	2001	86
10310400	Daggett Creek near Genoa, NV	5/9/1966	7/10/2001	31
10310500	Clear Creek near Carson City, NV	5/6/1948	11/29/2000	44
10311000	Carson River near Carson City, NV	5/12/1939	5/12/2001	63
10311100	Kings Canyon Creek near Carson City, NV	2/21/1977	10/11/2000	25
10311200	Ash Canyon Creek near Carson City, NV	10/1/1976	10/31/2000	23
10311450	Brunswick Canyon near New Empire, NV	8/2/1966	2000	34
10339400	Martis Creek near Truckee, CA	2/16/1959	3/6/2002	42
10340500	Prosser Creek below Prosser Creek Dam near Truckee, CA	1/21/1943	4/6/2002	60
10342000	Little Truckee River near Hobart Mills, CA	5/2/1947	5/31/1972	26
10343500	Sagehen Creek near Truckee, CA	4/22/1954	4/14/2002	49
10348900	Galena Creek near Steamboat, NV	7/20/1956	10/6/1993	34
10350100	Long Valley Creek near Happy Valley, NV	12/23/1955	6/30/2000	20

[1]Observation period incompletely specified in USGS data base

[2]Reese River has zero annual minimum flows for the minimum volume duration analysis, and was not used because log-Pearson III did not provide good explanation of estimated frequencies .

Table 2.4: Regional gages (see Blakemore et al., 1997) annual peak discharges data quality description

USGS ID	gage name	data flags	years affected
10265200	Convict Creek near Mammoth Lakes, CA	daily	1926,1974-1978
		R/D[1]	1964-1978
10265700	Rock Creek at Little Round Valley near Bishop, CA	daily	1975-1978
10267000	Pine Creek at Division Box near Bishop, CA	daily	1975-1978
10268700	Silver Canyon CREEK near Laws, CA	daily	1930-1943
		estimated	1974-1978
		R/D[1]	1975-1978
10276000	Big Pine Creek near Big Pine, CA	daily	1975-1978
10281800	Independence Creek below Pinyon Creek near Independence, CA	daily	1923-1951
10286000	Cottonwood Creek near Olancha, CA	daily	1908-1920,1973-1976
10287210	Bridgeport Creek near Bodie, CA		
10289000	Virginia Creek near Bridgeport, CA	R/D[1]	1954-1975
10291500	Buckeye Creek nr Bridgeport, CA		
10292000	Swauger C nr Bridgeport, CA	R/D[1]	1954-1975
10293000	E Walker River near Bridgeport, CA		
10295200	W Walker River at Leavitt Meadows near Coleville, CA	R/D[1]	1992-1996,1998-2001
10295500	Lower Walker River near Bridgeport, CA		
10296000	W Walker River below Lower Walker River Near Coleville, CA	estimate	1997
10296500	W Walker River near Coleville, CA	R/D[1]	1992-2001
10296800	Slinkard Creek tributary Near Topaz, CA		
10299100	Desert Creek near Wellington, NV	estimated	1997
10302010	Reese River Canyon near Schurz, NV	estimated	1986
10304500	Silver Creek below Pen Creek near Markleeville, CA		
10306000	Hot Springs Creek near Markleeville, CA		
10308100	Millberry Creek at Markleeville, CA		
10308200	E Fork Carson River below Markleeville Creek near Markleeville, CA	R/D[1]	1997-2001
10308800	Bryant Creek near Gardnerville, NV		
10309000	East Fork Carson River near Gardnerville, NV	month/day	1891
		estimated	1983
		R/D[1]	1890-1962, 1965-1988, 1990-1993, 1998-2001
10310000	West Fork Carson River at Woodfords, CA	R/D[1]	1992-2001
10310400	Daggett Creek near Genoa, NV		
10310500	Clear Creek near Carson City, NV	R/D[1]	1993-2001
10311000	Carson River near Carson City, NV	R/D[1]	1939-1986, 1991-2001
10311100	Kings Canyon Creek near Carson City, NV	R/D[1]	1977-1994
		R/D[2]	1995-2001
10311200	Ash Canyon Creek near Carson City, NV	estimated	1986
10311450	Brunswick Canyon near New Empire, NV	estimated	1986-1987, 1991-1993, 1996-1999
10339400	Martis Creek near Truckee, CA	R/D[2]	1971-2002
10340500	Prosser Creek below Prosser Creek Dam near Truckee, CA	daily	1943-1950
		estimated	1993
		R/D[2]	1963-2002
10342000	Little Truckee River near Hobart Mills, CA	R/D[1]	1947-1972
10343500	Sagehen Creek near Truckee, CA		
10348900	Galena Creek near Steamboat, NV	historic	1956
		R/D[1]	1962-1986, 1992-1994
10350100	Long Valley Creek near Happy Valley, NV	1999	estimated

Data flag notes: daily or monthly/daily value used for peak estimate, estimated indicates USGS provided an estimated value, R/D[1] indicates slight regulation and/or diversions, R/D[2] indicates significant regulation and/or diversions, historic indicates historic information available for peak

Table 2.5: Regional gages regulation effects on period of record used in regional analysis (comments on regulation)

USGS ID	gage name	flag	water year	begin	end
10265200	Convict Creek near Mammoth Lakes, CA	R/D[1]	1964-1978	5/21/1926	7/16/1978
	use period of record prior to 1964 because of Convict Lake				
10265700	Rock Creek at Little Round Valley near Bishop, CA		1975-1978	6/14/1927	6/9/1978
10267000	Pine Creek at Division Box near Bishop, CA		1975-1978	6/26/1922	5/27/1979
10268700	Silver Canyon CREEK near Laws, CA	R/D[1]	1975-1978	4/14/1930	6/22/1978
	no regulation occasional diversion use whole record				
10276000	Big Pine Creek near Big Pine, CA		1975-1978	7/15/1908	9/5/1978
10281800	Independence Creek below Pinyon Creek near Independence, CA		1923-1951	7/3/1923	7/27/1978
10286000	Cottonwood Creek near Olancha, CA		1908-1920,1973-1976	6/13/1906	9/10/1976
10287210	Bridgeport Creek near Bodie, CA			1/31/1963	1973-04-00
10289000	Virginia Creek near Bridgeport, CA	R/D[1]	1954-1975	4/14/1954	5/14/1975
	partial regulation by Virginia Lakes and other small lakes (small headwater lakes)				
10291500	Buckeye Creek nr Bridgeport, CA			5/20/1954	5/25/2001
10292000	Swauger C nr Bridgeport, CA	R/D[1]	1954-1975	3/9/1954	5/14/1975
	no regulation (small diversion)				
10293000	E Walker River near Bridgeport, CA			5/22/1923	5/12/2001
10295200	W Walker River at Leavitt Meadows near Coleville, CA	R/D[1]	1992-1996,1998-2001	5/20/1946	5/17/1970
10295500	Lower Walker River near Bridgeport, CA			2/2/1945	5/16/2001
10296000	W Walker River below Lower Walker River Near Coleville, CA		1997	12/11/1937	5/16/2001
10296500	W Walker River near Coleville, CA	R/D[1]	1992-2001	6/1/1903	5/17/2001
	slight regulation by Poor Lake Reservoir				
10296800	Slinkard Creek tributary Near Topaz, CA			1/31/1963	1973-00-00
10299100	Desert Creek near Wellington, NV		1997	8/17/1965	5/23/2000
10302010	Reese River Canyon near Schurz, NV		1986	1963[1]	6/28/1991
10304500	Silver Creek below Pen Creek near Markleeville, CA			5/2/1947	7/31/1973
10306000	Hot Springs Creek near Markleeville, CA			5/2/1947	6/1/1957
10308100	Millberry Creek at Markleeville, CA			1/31/1963	04/1973
10308200	E Fork Carson River below Markleeville Creek near Markleeville, CA	R/D[1]	1997-2001	1/2/1997	5/12/2001
	small reservoir regulation				
10308800	Bryant Creek near Gardnerville, NV			8/7/1961	4/22/2001
10309000	East Fork Carson River near Gardnerville, NV	R/D[1]	1890-1962, 1965-1988, 1990-1993, 1998-2001	5/28/1890	5/12/2001
	small amount reservoir regulation				
10310000	West Fork Carson River at Woodfords, CA	R/D[1]	1992-2001	1890[1]	2001
	small amount reservoir regulation				
10310400	Daggett Creek near Genoa, NV			5/9/1966	7/10/2001
10310500	Clear Creek near Carson City, NV	R/D[1]	1993-2001	5/6/1948	11/29/2000
10311000	Carson River near Carson City, NV	R/D[1]	1939-1986, 1991-2001	5/12/1939	5/12/2001
	flow slightly regulated by several small reservoirs				
10311100	Kings Canyon Creek near Carson City, NV	R/D[2]	1995-2001	2/21/1977	10/11/2000
	omit this gage because flag is for significant regulation				

Data flag notes: daily or monthly/daily value used for peak estimate, estimated indicates USGS provided an estimated value, R/D^1 indicates slight regulation and/or diversions, R/D^2 indicates significant regulation and/or diversions, historic indicates historic information available for peak

Table 2.5: Regional gages regulation effects on period of record used in regional analysis (comments on regulation)(continued)

10311200	Ash Canyon Creek near Carson City, NV		1986	10/1/1976	10/31/2000
10311450	Brunswick Canyon near New Empire, NV		1986-1987, 1991-1993, 1996-1999	8/2/1966	2000
10339400	Martis Creek near Truckee, CA	R/D[2]	1971-2002	2/16/1959	3/6/2002
	presume dam at Martis Creek Lake was placed in after 1970, the lake may make this gage not relevant to the rest of the data				
10340500	Prosser Creek below Prosser Creek Dam near Truckee, CA	R/D[2]	1963-2002	1/21/1943	4/6/2002
	period of record after dam should be excluded				
10342000	Little Truckee River near Hobart Mills, CA	R/D[1]	1947-1972	5/2/1947	5/31/1972
	only affected by a trans-mountain diversion				
10343500	Sagehen Creek near Truckee, CA			4/22/1954	4/14/2002
10348900	Galena Creek near Steamboat, NV	R/D[1]	1962-1986, 1992-1994	7/20/1956	10/6/1993
	only affected by a diversion				
10350100	Long Valley Creek near Happy Valley, NV			12/23/1955	6/30/2000

R/D[1] indicates slight regulation and/or diversions, R/D[2] indicates significant regulation and/or diversions

Table 2.6: Lake Tahoe Basin stream gages annual peak discharges period of record, years recorded

USGS ID	Description	begin	end	years
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	6/4/1991	5/11/2001	11
10336600	Upper Truckee River near Meyers, CA	1961	3/8/1986	26
103366092	Upper Truckee River at Highway 50 above Meyers, CA	5/25/1991	5/15/2001	11
10336610	[1]Upper Truckee River at South Lake Tahoe, CA	1972	2000	25
10336626	Taylor Creek near Camp Richardson, CA	5/28/1969	4/30/1992	24
10336635	Lake Tahoe Tributary near Meeks Bay	1/31/1963	1/12/1973	11
10336630	Eagle Creek near Camp Richardson, CA	5/31/1972	11/12/1973	3
10336640	Meeks Creek at Meeks Bay, CA	5/15/1972	6/1/1975	4
10336645	General Creek near Meeks Bay, CA	4/30/1981	4/14/2002	22
10336650	Quail Lake Creek at Homewood Bay, CA	5/14/1972	5/7/1974	3
10336658	Madden Creek at Homewood, CA	5/31/1972	5/17/1973	2
10336660	Blackwood Creek near Tahoe City, CA	5/10/1961	4/14/2002	42
10336674	Ward Creek below Confluence near Tahoe City, CA	4/17/1992	5/30/2002	11
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	4/17/1992	5/15/2001	10
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	5/16/1973	4/14/2002	30
10336693	Wood Creek near Crystal Bay, NV	5/1967	5/1987	12
10336686	Carnelian Creek at Carnelian Bay, CA	5/22/1999	4/27/2000	2
10336689	Snow Creek at Tahoe Vista, CA	3/25/1981	4/15/1985	5
10336698	Third Creek near Crystal Bay, NV			0
103366993	[1]Incline Creek above Tyrol Village near Incline Village, NV			0
103366995	[1]Incline Creek at Hwy 28 at Incline Village, NV			0
10336700	[1]Incline Creek near Crystal Bay, NV			0
10336715	Marlette Creek near Carson City, NV	7/30/1974	4/21/2001	28
10336730	Glenbrook Creek at Glenbrook, NV	3/3/1972	5/19/2001	18
10336740	Logan House Creek nr Glenbrook, NV	5/10/1984	4/25/2001	18
10336756	Edgewood Creek Tributary near Daggett Pass. NV	4/24/1991	2000-04-00	10
10336758	[1]Edgewood Creek Tributary at Highland Tributary near Tahoe Village, NV			0
103367585	Edgewood Creek at Palisade Drive nearr Kingsbury, NV	8/14/1991	3/28/2001	11
103367592	Eagle Rock Creek nr Stateline, NV	2/3/1990	2/13/2000	11
10336760	Edgewood Creek at Stateline, NV	5/3/1993	5/30/2001	9
10336765	Edgewood Creek at Lake Tahoe near Stateline, NV	8/27/1990	10/26/1991	3
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	6/3/1991	5/24/2000	10
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	9/18/1990	5/12/2001	12
10336780	Trout Creek near Tahoe Valley, CA	6/14/1961	2/14/2000	40
10336785	Heavenly Valley Creek near Tahoe Valley, CA			0
10336790	Trout Creek at South Lake Tahoe, CA	6/4/1972	6/7/1974	3

[1]Ony daily stream flow data available

Table 2.7: Lake Tahoe Basin stream gages, annual peak discharges data quality description

USGS ID	Description	data flags	water year
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA		
10336600	Upper Truckee River near Meyers, CA		
103366092	Upper Truckee River at Highway 50 above Meyers, CA		
10336610	Upper Truckee River at South Lake Tahoe, CA		
10336626	Taylor Creek near Camp Richardson, CA		
10336635	Lake Tahoe Tributary near Meeks Bay		
10336630	Eagle Creek near Camp Richardson, CA		
10336640	Meeks Creek at Meeks Bay, CA		
10336645	General Creek near Meeks Bay, CA		
10336650	Quail Lake Creek at Homewood Bay, CA		
10336658	Madden Creek at Homewood, CA		
10336660	Blackwood Creek near Tahoe City, CA		
10336674	Ward Creek below Confluence near Tahoe City, CA		
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	estimated	1994
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA		
10336693	Wood Creek near Crystal Bay, NV		
10336686	Carnelian Creek at Carnelian Bay, CA		
10336689	Snow Creek at Tahoe Vista, CA		
10336698	Third Creek near Crystal Bay, NV		
103366993	Incline Creek above Tyrol Village near Incline Village, NV		
103366995	Incline Creek at Hwy 28 at Incline Village, NV		
10336700	Incline Creek near Crystal Bay, NV		
10336715	Marlette Creek near Carson City, NV	daily	1975
		R/D[1]	1982, 1994,
		R/D[2]	1974-1979, 1983, 1987-1989,1992-1993, 1995-2001
		historic	1983
		exceeded	1979
10336730	Glenbrook Creek at Glenbrook, NV	R/D[1]	1972-1975
10336740	Logan House Creek nr Glenbrook, NV		
10336756	Edgewood Creek Tributary near Daggett Pass. NV	daily	1991
		date/day	1994,1996-1997,2000
10336758	Edgewood Creek Tributary at Highland Tributary near Tahoe Village, NV		
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	R/D[1]	1993-2001
103367592	Eagle Rock Creek nr Stateline, NV		
10336760	Edgewood Creek at Stateline, NV		
10336765	Edgewood Creek at Lake Tahoe near Stateline, NV	R/D[1]	1991
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA		
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA		
10336780	Trout Creek near Tahoe Valley, CA		
10336785	Heavenly Valley Creek near Tahoe Valley, CA		
10336790	Trout Creek at South Lake Tahoe, CA		

Data flag notes: daily or monthly/daily value used for peak estimate, estimated indicates USGS provided an estimated value, R/D[1] indicates slight regulation and/or diversions, R/D[2] indicates significant regulation and/or diversions, historic indicates historic information available for peak

Table 2.8: Regional gages daily discharges period of record, years recorded

USGS ID	gage name	begin	end	years
10265200	Convict Creek near Mammoth Lakes, CA	10/1/1959	9/30/1975	16.0
10276000	Big Pine Creek near Big Pine, CA	10/1/1920	9/30/1978	58.0
10281800	Independence Creek below Pinyon Creek near Independence, CA	1/1/1923	9/30/1978	55.8
10282480	Mazourka Creek near Independence, CA	10/1/1960	9/30/1972	12.0
10286000	Cottonwood Creek near Olancha, CA	1/1/1906	9/30/1978	57.1
10289000	Virginia Creek near Bridgeport, CA	10/1/1953	9/30/1975	22.0
10291500	Buckeye Creek near Bridgeport, CA	4/1/1911	9/30/2002	34.5
10292000	Swauger Creek near Bridgeport, CA	10/1/1953	9/30/1975	22.0
10293000	E Walker River near Bridgeport, CA	10/1/1921	9/30/2002	80.2
10295200	W Walker River at Leavitt Meadows near Coleville, CA	7/1/1945	9/30/1964	19.3
10295500	Lower Walker River near Bridgeport, CA	10/1/1944	9/30/2002	48.0
10296000	W Walker River below Lower Walker River Near Coleville, CA	4/1/1938	9/30/2002	64.5
10296500	W Walker River near Coleville, CA	10/1/1902	9/30/2002	75.3
10299100	Desert Creek near Wellington, NV	12/1/1964	9/30/1969	4.8
10301000	West Fork Carson River at Woodfords, CA	12/1/1910	10/31/1922	6.4
10302010	Reese River Canyon near Schurz, NV	10/1/1966	9/30/1977	11.0
10304500	Silver Creek below Pen Creek near Markleeville, CA	10/1/1946	9/30/1967	21.0
10308200	E Fork Carson River below Markleeville Creek near Markleeville, CA	9/1/1960	9/30/2002	42.1
10308800	Bryant Creek near Gardnerville, NV	6/1/1961	9/30/2002	19.8
10309000	East Fork Carson River near Gardnerville, NV	1890-01-01	9/30/2002	81.3
10310000	West Fork Carson River at Woodfords, CA	9/30/1900	9/30/2002	71.0
10310400	Daggett Creek near Genoa, NV	10/29/1965	9/30/2002	31.8
10310500	Clear Creek near Carson City, NV	3/1/1948	9/30/2002	28.3
10311000	Carson River near Carson City, NV	5/12/1939	9/30/2002	63.4
10311100	Kings Canyon Creek near Carson City, NV	6/1/1976	9/30/2002	26.4
10311200	Ash Canyon Creek near Carson City, NV	7/1/1976	9/30/2002	26.3
10336600	Upper Truckee River near Meyers, CA	10/1/1960	9/30/1986	26.0
10336660	Blackwood Creek near Tahoe City, CA	10/1/1960	9/30/2002	42.0
10336780	Trout Creek near Tahoe Valley, CA	10/1/1960	9/30/2002	42.0
10339400	Martis Creek near Truckee, CA	10/1/1958	9/30/2002	41.4
10340500	Prosser Creek below Prosser Creek Dam near Truckee, CA	10/1/1942	9/30/2002	59.5
10342000	Little Truckee River near Hobart Mills, CA	1/1/1947	10/10/1972	25.8
10343500	Sagehen Creek near Truckee, CA	10/1/1953	9/30/2002	49.0
10348900	Galena Creek near Steamboat, NV	10/1/1961	9/30/1994	33.0

Table 2.9: Regional gages description of regulation and diversions important for low-flow and flow-duration analysis

USGS ID	gage name	regulation/diversion
10265200	Convict Creek near Mammoth Lakes, CA	
10276000	Big Pine Creek near Big Pine, CA	some regulation by Convict Lake, no diversions
10281800	Independence Creek below Pinyon Creek near Independence, CA	diversion for power and irrigation, surface flow does not always reach gage
10282480	Mazourka Creek near Independence, CA	no regulation or diversion
10286000	Cottonwood Creek near Olancha, CA	no regulation or diversion
10289000	Virginia Creek near Bridgeport, CA	diversion cottonwood power house combined creek and power house discharge show significant diversion
10291500	Buckeye Creek near Bridgeport, CA	partly regulated by Virginia Lakes, diversion for irrigation of about 3,000 acres above station
10292000	Swauger Creek near Bridgeport, CA	no regulation or diversion
10293000	E Walker River near Bridgeport, CA	diversion for irrigation of about 1000 acres
10295200	W Walker River at Leavitt Meadows near Coleville, CA	some regulation Bridgeport Reservoir
10295500	Lower Walker River near Bridgeport, CA	
10296000	W Walker River below Lower Walker River Near Coleville, CA	
10296500	W Walker River near Coleville, CA	few small ranch ditch diversions, slight regulation by Poor Lake Reservoir
10299100	Desert Creek near Wellington, NV	few small ranch ditch diversions, slight regulation by Poor Lake Reservoir
10301000	West Fork Carson River at Woodfords, CA	partial regulation by few small reservoirs, storage capacity 1700 ac-ft
10302010	[1]Reese River Canyon near Schurz, NV	
10304500	Silver Creek below Pen Creek near Markleeville, CA	no regulation
10308200	E Fork Carson River below Markleeville Creek near Markleeville, CA	flows partially regulated by three small reservoirs total capacity about 1700 ac-ft
10308800	Bryant Creek near Gardnerville, NV	few small diversion, small reservoirs 5,000 ac-ft
10309000	East Fork Carson River near Gardnerville, NV	no diversions
10310000	West Fork Carson River at Woodfords, CA	diversion for irrigation, small reservoir regulation, 5,000 ac-ft
10310400	Daggett Creek near Genoa, NV	one small diversion for irrigation, few small reservoirs, 1500 ac-ft
10310500	Clear Creek near Carson City, NV	no diversions, since 1968 includes pumped dry weather flow from Lake Tahoe, Douglas County Sewer Improvement District
10311000	Carson River near Carson City, NV	many diversion for irrigation, flow slightly regulated by several small reservoirs
10311100	Kings Canyon Creek near Carson City, NV	many diversion for irrigation, flow slightly regulated by several small reservoirs
10311200	Ash Canyon Creek near Carson City, NV	
10339400	Martis Creek near Truckee, CA	minor diversions for local water supply
10340500	Prosser Creek below Prosser Creek Dam near Truckee, CA	regulation by Martis Creek Lake since 1971
10342000	Little Truckee River near Hobart Mills, CA	flows regulate by Prosser Creek Dam since January 31, 1963
10343500	Sagehen Creek near Truckee, CA	one trans-mountain diversion to Sierra Valley above station
10348900	Galena Creek near Steamboat, NV	no storage or diversion

[1]Reese River has zero annual minimum flows for the minimum volume duration analysis, and was not used because log-Pearson III did not provide good explanation of estimated frequencies .

Table 2.10: Lake Tahoe Basin stream gages daily discharges period of record, years recorded

USGS ID	Description	begin	end	years
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	5/12/1990	9/30/2002	12.4
10336600	Upper Truckee River near Meyers, CA	10/1/1960	9/30/1986	26.0
103366092	Upper Truckee River at Highway 50 above Meyers, CA	6/1/1990	9/30/2002	12.3
10336610	[1]Upper Truckee River at South Lake Tahoe, CA	1972	2000	25
10336626	Taylor Creek near Camp Richardson, CA	10/1/1968	12/14/1992	24.2
10336630	Eagle Creek near Camp Richardson, CA	10/1/1971	9/30/1974	3.0
10336640	Meeks Creek at Meeks Bay, CA	10/1/1971	7/31/1975	3.3
10336645	General Creek near Meeks Bay, CA	7/7/1980	9/30/2002	22.2
10336650	Quail Lake Creek at Homewood Bay, CA	10/1/1971	9/30/1974	3.0
10336658	Madden Creek at Homewood, CA	10/1/1971	9/30/1973	2.0
10336660	Blackwood Creek near Tahoe City, CA	10/1/1960	9/30/2002	42.0
10336674	Ward Creek below Confluence near Tahoe City, CA	10/1/1991	9/30/2002	11.0
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	10/1/1991	9/30/2001	10.0
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	10/1/1972	9/30/2002	30.0
10336686	Carnelian Creek at Carnelian Bay, CA	5/1/1999	9/30/2000	1.4
10336689	Snow Creek at Tahoe Vista, CA	7/30/1980	9/30/1985	5.2
10336698	Third Creek near Crystal Bay, NV	10/1/1969	9/30/2002	29.7
103366993	Incline Creek above Tyrol Village near Incline Village, NV	5/1/1990	9/30/2002	12.4
103366995	Incline Creek at Hwy 28 at Incline Village, NV	12/28/1989	9/30/2002	12.8
10336700	Incline Creek near Crystal Bay, NV	10/1/1969	9/30/2002	19.7
10336715	Marlette Creek near Carson City, NV	10/1/1973	9/30/2002	29.0
10336730	Glenbrook Creek at Glenbrook, NV	10/1/1971	9/30/2002	18.9
10336740	Logan House Creek nr Glenbrook, NV	10/1/1983	9/30/2002	19.0
10336756	Edgewood Creek Tributary near Daggett Pass. NV	1/1/1981	9/30/1983	2.7
10336758	Edgewood Creek Tributary at Highland Tributary near Tahoe Village, NV	1/1/1981	9/30/1983	2.7
103367585	Edgewood Creek at Palisade Drive nearr Kingsbury, NV	10/1/1989	9/30/2001	12.0
103367592	Eagle Rock Creek nr Stateline, NV	11/18/1989	9/30/2002	11.0
10336760	Edgewood Creek at Stateline, NV	10/1/1992	9/30/2002	10.0
10336765	Edgewood Creek at Lake Tahoe near Stateline, NV	4/12/1989	9/30/1992	3.5
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	5/22/1990	9/30/2002	12.4
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	6/1/1990	9/30/2002	12.3
10336780	Trout Creek near Tahoe Valley, CA	10/1/1960	9/30/2002	42.0
10336785	Heavenly Valley Creek near Tahoe Valley, CA	10/1/1988	11/15/1992	4.1
10336790	Trout Creek at South Lake Tahoe, CA	10/1/1971	9/30/1992	7.0

Table 2.11: Lake Tahoe Basin stream gages, annual peak discharges data quality description, years with quality flags

USGS ID	Description	[2]Regulation/Diversion	[3]Flag
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	diversion from Echo Lake	1,e
10336600	Upper Truckee River near Meyers, CA	diversion from Echo Lake	e
103366092	Upper Truckee River at Highway 50 above Meyers, CA	diversion from Echo Lake	1,e
10336610	Upper Truckee River at South Lake Tahoe, CA	diversion from Echo Lake	
10336626	Taylor Creek near Camp Richardson, CA	Fallen leaf lake dam regulated for fisheries	e
10336630	Eagle Creek near Camp Richardson, CA	natural spring	
10336640	Meeks Creek at Meeks Bay, CA	natural spring	
10336645	General Creek near Meeks Bay, CA	natural spring	1,e
10336650	Quail Lake Creek at Homewood Bay, CA	(limited period of record)	
10336658	Madden Creek at Homewood, CA	might have some diversion	
10336660	Blackwood Creek near Tahoe City, CA	natural	1,e,E
10336674	Ward Creek below Confluence near Tahoe City, CA	natural	1,e
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	natural	1,e
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	natural	1,e
10336686	Carnelian Creek at Carnelian Bay, CA	(limited period of record)	e
10336689	Snow Creek at Tahoe Vista, CA	recent restoration project (within last three years)	
10336698	Third Creek near Crystal Bay, NV	Incline Lake regulation	1,e
103366993	Incline Creek above Tyrol Village near Incline Village, NV	natural	1,e
103366995	Incline Creek at Hwy 28 at Incline Village, NV	natural	1,e
10336700	Incline Creek near Crystal Bay, NV	natural	1,e
10336715	Marlette Creek near Carson City, NV	regulated but probably does not affect low flows	1,e
10336730	Glenbrook Creek at Glenbrook, NV	natural	1,e
10336740	Logan House Creek nr Glenbrook, NV	natural	1,e
10336756	Edgewood Creek Tributary near Daggett Pass. NV	(limited period of record)	
10336758	Edgewood Creek Tributary at Highland Tributary near Tahoe Village, NV	(limited period of record)	e
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	gage moved, affected by retention structure, backwater	1,e
103367592	Eagle Rock Creek nr Stateline, NV	natural	1,e
10336760	Edgewood Creek at Stateline, NV	gage moved affected by retention structure, backwater	1,e
10336765	Edgewood Creek at Lake Tahoe near Stateline, NV		1,e
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	Lake Christopher on tributary removed about 10 years ago	1,e
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	Lake Christopher on tributary removed about 10 years ago	1,e
10336780	Trout Creek near Tahoe Valley, CA	Lake Christopher on tributary removed about 10 years ago	1,e
10336785	Heavenly Valley Creek near Tahoe Valley, CA	(limited period of record)	1,e
10336790	Trout Creek at South Lake Tahoe, CA	Lake Christopher on tributary removed about 10 years ago	e

[1]Description provided (personal communication), Rita Whitney, Tahoe Regional Planning Authority (12 July 2004)
[2]Flags from U.S. Geological Survey data base, annual daily flow values
1 – U.S. Geological Survey data base quality flags, data value is write-protected, no remark given
e – U.S. Geological Survey data base quality flags, estimated value, write protected
E – U.S. Geological Survey data base quality flags, Measurement quality excellent

2.3. Watershed and meteorological parameters

The independent variables used for the regression analysis were developed using ARCINFO GIS technology. Table 2.12 provides the variables developed, data source and the method/data source used to develop the parameters.

Table 2.12: Independent variable summary

variable	data source	method
drainage area (sq mi)	[2]USGS	USGS data base
basin average elevation (ft msl)	[3]PRISM	PRISM/GIS software
basin average mean annual precipitation (inches)	PRISM	PRISM/GIS software
basin average snowfall (inches)	PRISM	PRISM/GIS software
basin average mean annual temperature (^{o}F)	PRISM	PRISM/GIS software
[1]basin average precipitation DDF	[4]NOAA-14	GIS software

[1]Depth-duration-frequency, 2hr and 24hr duration, for 50%, 10%, 4%, 2% and 1%
[2]USGS, 2004, [3]Daly et al., 2004, [4]Bonnin, 2004

3. Basic flow frequency relationships

The purpose of the regional frequency analysis is to develop predictive relationships between watershed physical characteristics and relevant meteorologic characteristics on the one hand and flow quantiles (e.g., the 1% chance peak flow) on the other hand for the following types of distributions:

- Flow-duration frequency curves
- Annual peak and volume duration frequency curves
- Annual low-flow (minimum) 7day volume duration frequency curves

A flow duration curve gives the percent of time that a flow level will be exceeded in a period.(see Mosley and Mckerchar, pg. 8.26, 1992, and Stedinger et al., pg 18.53, 1992). For example, an annual daily flow duration curve gives the percentage of days in a year that the average daily flow will exceed a specific level. The flow duration curve shown in Figure 3.1 shows that annual average daily stream flow will exceed a little more than 10.0 cfs 80% of the time during the year (i.e., the daily flows will exceed about 10.0 cfs for 0.80*365 days per year). Figure 3.2 shows flow estimates interpolated at regular exceedance intervals.

Flow duration curves traditionally have application to estimating hydropower for run of river power plants, water supply for small fraction users, and as an overall measure of the hydrologic characteristics of a river. In the Lake Tahoe Basin, an average annual sediment load contribution of a particular stream might be computed by integrating the concentration of sediment associated with a daily stream flow with the flow duration curve might be of interest.

Annual peak and volume duration frequency curves, give the probability that the maximum peak or consecutive nday average flow will exceed a particular flow level in a year (see, IACWD, 1982 and Stedinger et al. section 18, 1992, U.S. Army Corps of Engineers, 1993). For example, the volume duration frequency curves in figure 3.3 show that there is a 20% chance (0.02 exceedance probability) that the 1day annual maximum flow will exceed 800 cfs/day, a 4% chance that the 7day will exceed 700 cfs, and a 2% chance that the 30day will exceed 600 cfs/day.

Mathematically, this probability is expressed as:

$$P\left[Q_{max} > q\right] = p$$

where: P[ ] is the probability of the expression in the brackets, Q_{max} is the annual maximum flow, q is the level of flow, and p is the exceedance probability (the probability that Q_{max} will exceed q in a year). [Notice here that most books on statistics quantify probability as a cumulative value, or equivalently, the probability of being less than a value. Hydrologists generally refer to this cumulative probability as a non-exceedance probability.]

Annual peak and volume duration frequency curves are important for sizing flow conveyance and storage facilities, assessing flood risks and delineating floodplain boundaries.

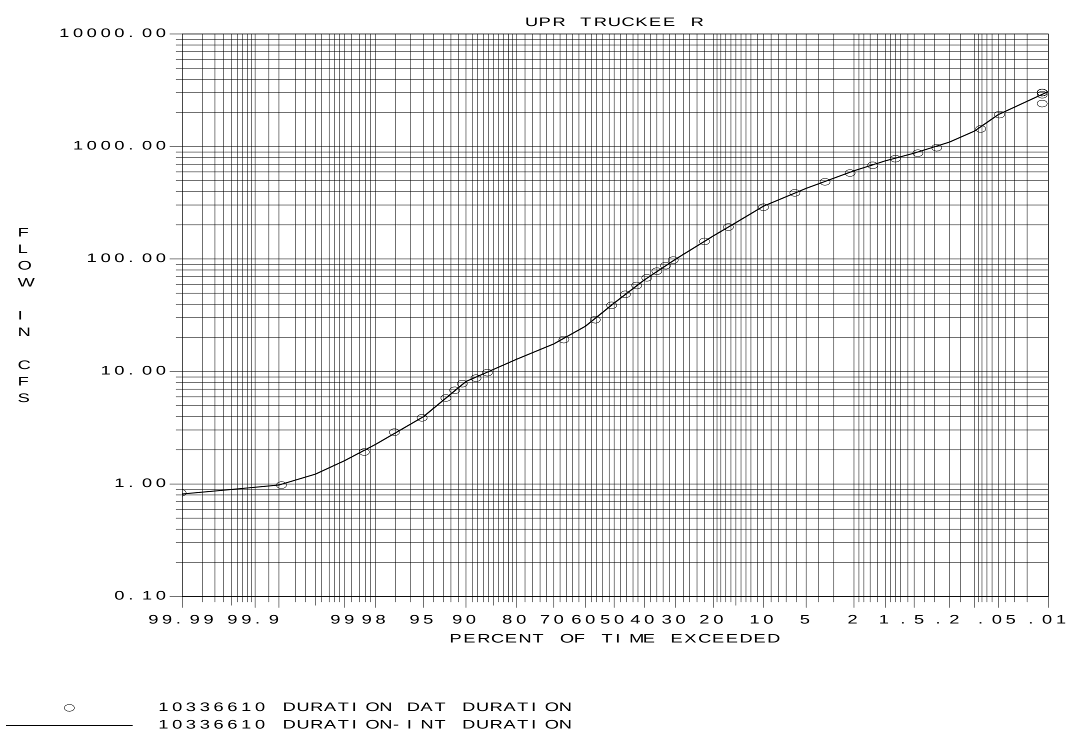

Figure 3.1: Annual daily flow duration curve with cubic spline fit to empirical frequencies, log-normal probability scale Upper Truckee River, USGS gage ID 10336610

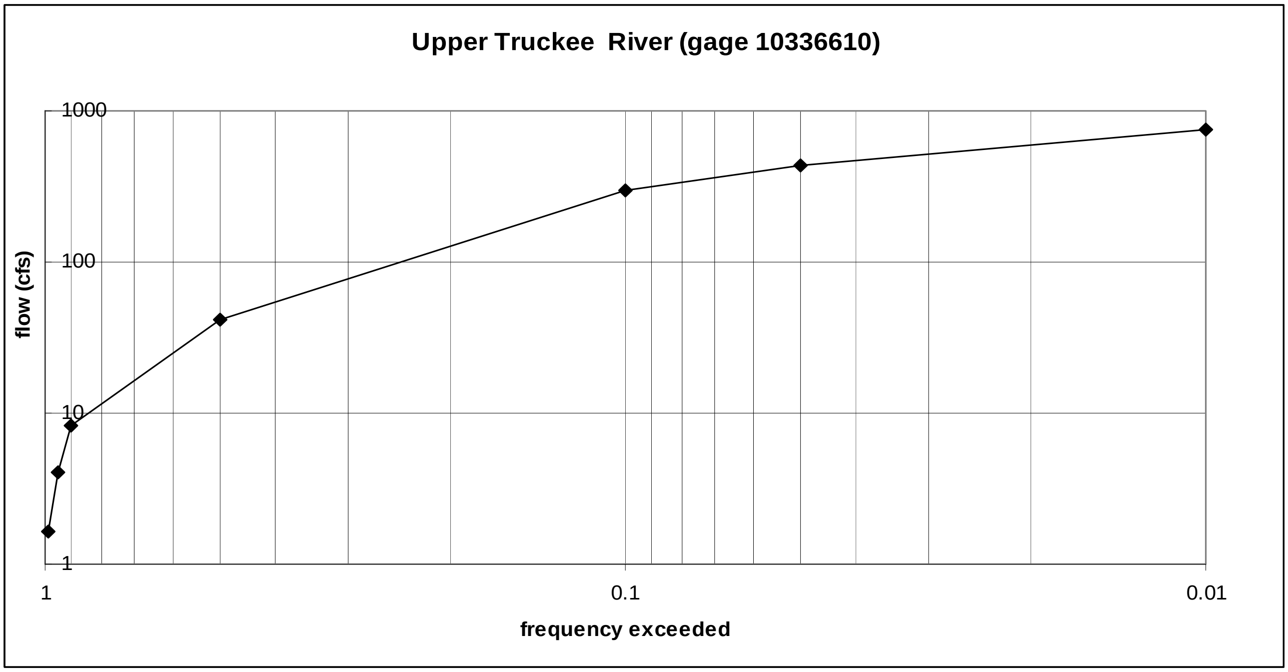

Figure 3.2: Upper Truckee River (USGS gage 10336610) flow duration curve showing interpolated points at specified frequency exceeded (log-log scale)

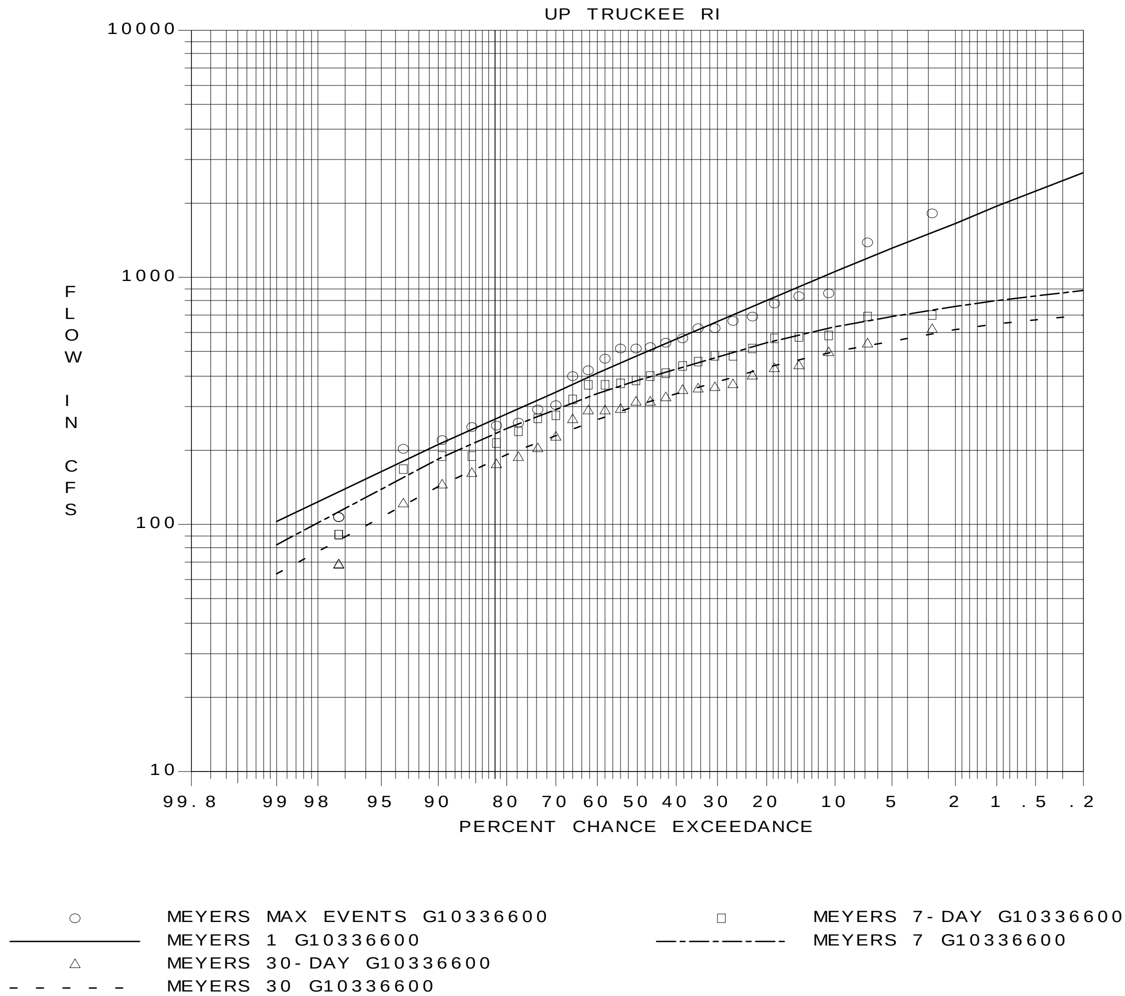

Figure 3.3: Maximum annual 1, 7 and 30 day empirical (plotting position) and log-Pearson III flow frequency curves, Upper Truckee River at Meyers, USGS gage 10336600

Finally, a low-flow frequency curves express the probability than the annual minimum consecutive nday flow will be less than a given value (see Stedinger et al. pg. 18.53, 1992) in any year. For example, the frequency curve in figure 3.4 show that there is a 10% chance (0.10 non-exceedance probability) that the annual minimum 7day flow will not exceed 0.5 cfs/day.

Mathematically, this probability is expressed as:

$$P\left[Q_{low} < q\right] = p$$

where p is now a non-exceedance probability. Low-flow frequency curves have applications to setting water quality standards for streams (e.g., the 7day-10year (0.1 annual non-exceedance probability)).

Important differences between these different types of curves are as follows:

- Probability distributions are inferred from the relative frequency of gage flow data to describe peak and volume duration frequency curves. The same is true for low-flow frequency curves, except the non-linearity exhibited by the empirical frequency curve (the plotting positions) makes it difficult to describe very low flows with a simple analytic distribution. Generally speaking, flow-duration curves are only described by the empirical frequencies (the relative frequency of the observed daily data). However, sometime a distribution can be used to describe the curve for observations exceeding a given level. In the western U.S., distributions are often found for values exceeding zero cfs/day.
- Regional analysis is commonly used to relate watersheds characteristics and meteorologic variables to characteristics of peak and volume duration frequency curves.. Applications to low-flow frequency curves have been performed with varying degrees of success. Regional analysis has generally not been applied to flow-duration frequency curves.

Consequently, the planned regional study focused on a standard application with annual peak and volume duration frequency curve, but faced some interesting challenges with regard to finding a regional description of low-flow and flow-duration frequency curves.

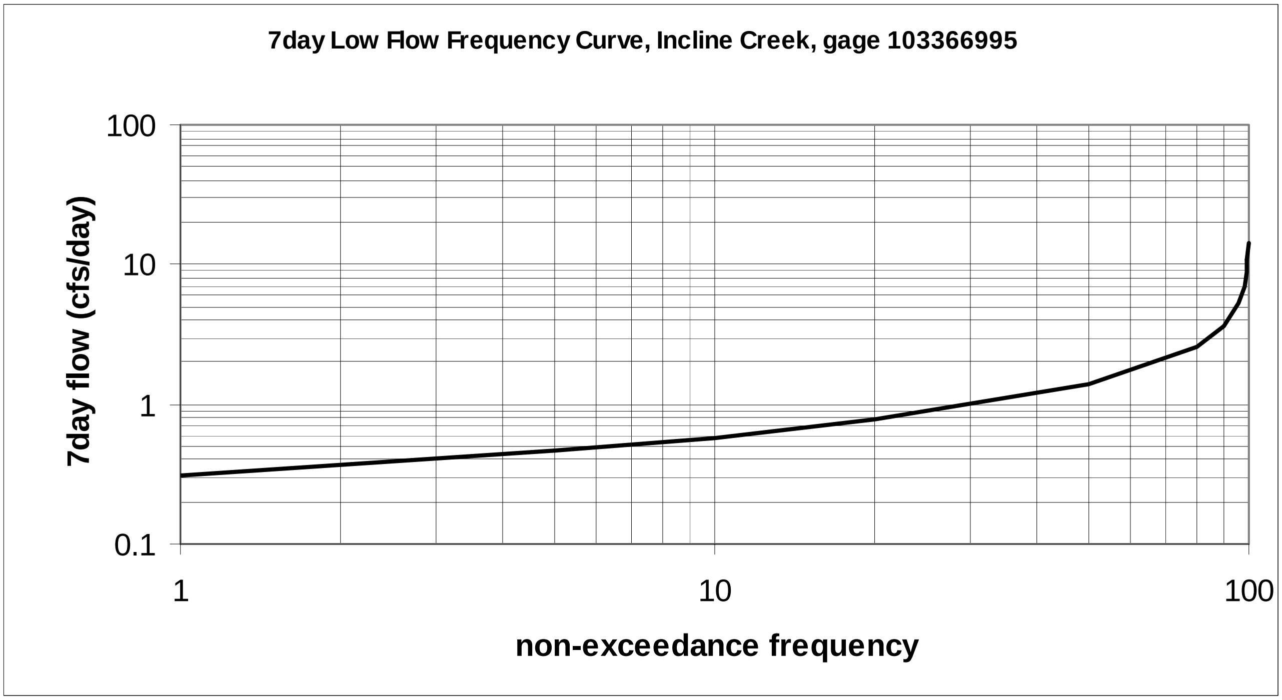

Figure 3.4: Annual 7day low-flow frequency curves, Incline Creek, USGS gage 103366995

4. Regional frequency analysis methods

4.1. Introduction

This section is devoted to a general discussion of the methods that will be used to estimate frequency curves from gage data and regionalizing the results by relating the quantiles or parameters of the frequency curve to watershed characteristics and meteorologic parameters. A number of different techniques needed to be explored given the range and duration of flow frequencies that were investigated. Detailed technical description of the methods are provided in section 11, the technical appendix.

Scaling the frequency curve by some parameter (such as the median) is the simplest approach that was investigated (see section 4.2). In this approach, a single non-dimensional frequency curve is determined in a region, and the scaling parameter is regionalized. Alternatively, frequency curve quantiles (e.g., the flow for the 1% chance exceedance event) are related to some watershed characteristic by regression. Annual peak flow quantiles are regionalized by the U.S. Geological Survey in this manner for every state in the country (see section 4.3).

Selecting between the various regional estimates will be judged using prediction error measures. The prediction error will be measured base on both standard measures from regression theory and split sample testing (see section 4.4).

4.2. Scaling frequency curves

The approach to scaling frequency curves can be developed by considering the basic frequency curve equation:

$$Q_p = \overline{X} + k_p(S) \tag{4.1}$$

where Q_p is the flow quantile for probability p, $\overline{X}$ is the mean flow, S is the standard deviation, and k_p is a frequency factor that depends on the distribution being used to model the stream flows. Choosing the mean as a scaling factor, divide both sides of the above equation by $\overline{X}$ to obtain:

$$Q_p^* = 1.0 + k_p\left(\frac{S}{\overline{X}}\right) = 1.0 + k_p(C_v) \tag{4.2}$$

where Q_p^* is the scaled or dimensionless discharge, and C_v is the coefficient of variation.

The problem with this formulation is that the mean is more strongly correlated with drainage area than the standard deviation, causing the coefficient of variation to decrease with drainage area. This prevents a single dimensionless frequency from describing the frequency within a region. However, as is true for most hydrologic models, including frequency curves, the representation might be used as an approximation if C_v does not vary too greatly. Hosking and Wallis (1997) have argued for this approach and applied it successfully in a number of applications. Consequently, attempting to scale frequency curves may have potential. This would include using drainage area in place of the mean, since these values are highly correlated.

4.3. Regression approach

Application of linear regression analysis is the most prevalent approach to relating flow frequency to regional watershed and meteorologic characteristics. The equations will take the form:

$$\log_{10}\left(Q_p\right) = b_0 + b_1\log_{10}\left(X_1\right) + b_2\log_{10}\left(X_2\right) + \ldots e \qquad (4.3)$$

where Q_p, the dependent variable, is the flow quantile or flow distribution parameter, the X_i are the independent variables representing regionalizing characteristics (e.g., drainage area, stream length, mean annual precipitation), b_i are the regression coefficients to be determined from the observations and e is a random residual measuring the inability of the regression to account for the variation in the dependent variable. The log transform is almost always performed to linearize the non-linear relationship between flow magnitudes and both watershed and meteorologic characteristics.

Standard application of regression analysis to obtain the b_i is termed **ordinary least squares (OLS)**. Ideally, the random residual, **e**, would be uncorrelated among the predictions of the flow quantiles at gage sites, and of equal spread (or variance). Unfortunately, neither is true for flow data. Rather, flow quantiles tend to be correlated regionally. Furthermore, the spread or variance is a function of gage record length (statistical sampling error) at each gage. The error variance will most likely be unequal given the varying record length available at each gage. Consequently, **generalized least squares (GLS)** needs to be employed to estimate the regression coefficients. The equation has the same form as for OLS, but the regression parameters need to be determined using a different approach.

Standard software is not available for applying **GLS**. However, software has been developed for **GLS** applications within the Corps. The strategy for applying this software will be to use the standard software employing **OLS** to obtain a first approximation to the most important independent variables to use in the regression. This software is useful because it is designed to readily combine various independent variables, and transforms of the data, to efficiently analyze possible regressions. Once the most important variables have been identified, **GLS** can be employed to obtain a best equation. For a more detailed discussion of the difference between OLS and GLS see section 11, the technical appendix.

Note that the advantage of GLS over OLS is that a better estimate of predictive capability of the regression is obtained with GLS given the correlation and unequal variance in the residuals. Typically, however, the difference in the regression coefficients obtained is not great (see Stedinger and Tasker, 1986)

4.4. Selecting a regional relationship

The regional relationship will be selected based on the average prediction error, R^2 and standard error. These measures will be obtained for both the full data set and in split sample testing. Split sample testing is particularly important because it measures the ability of the regional relationship to estimate future relative frequencies (i.e., future exceedance or non-exceedance of some design level). This approach was used by the Water Resources Council to choose among competing distribution/estimation pairings in developing the federal guidelines for performing flood frequency analysis (see IACWD, 1982). The problem with the split sampling approach is there is a limited number of gages with long enough records to show a statistically significant difference between various approaches.

The standard error and R^2 measures are well defined in terms of regression analysis. Standard error is the square root of the unbiased estimate of the regression residuals. The relative error will be measure by the multiple regression R^2 (multiple coefficient of determination) = 1-(standard error)^2/(variance of the dependent variable). Average prediction error is a more difficult concept that arises from the application of GLS, but is similar in concept to standard error. For a further discussion of these measures see section 11, the technical appendix

These measures will be used to judge both the number of gages and parameters that should be used in the final regional relationships. The relationships will be judged both in terms of the magnitude of the error measures, and the statistical significance of adding additional parameters or gages to improve predictive capability.

5. Exploratory Data Analysis

5.1. Introduction

The purpose of this section is to explore the general characteristics of the gage data and how these characteristics vary regionally. This type of analysis is useful for assessing the potential for regional analysis, identifying potential data problems and gaining an overall understanding of the region-wide variation in stream flow characteristics. The general runoff characteristics of runoff are explored by examining: 1) the seasonal pattern of runoff in section 5.2; 2) the coefficient of variation in annual maximum 1day flow values in section 5.3; 3) flow and stage trends in section 5.4, and finally, 4) in section 5.4, the characteristics of Lake Tahoe Basin flow duration curves.

5.2. Seasonal Distribution of Runoff

Seasonal distribution of runoff for the study gages was examined by determining the frequency of starting dates of the annual maximum 1day and 30day flows and the 7day low-flow values. Figure 5.1 -5.6 show histograms of start dates for gages that represent runoff across the Lake Tahoe Basin and gages extending from north to south in the analysis region. As can be seen from figure 5.1, 5.3, and 5.5, starting dates for flow events do not vary across the Tahoe Basin. The remaining comparisons between Lake Tahoe and regional gages to the south show very similar patterns in the seasonality of the runoff. There is some noticeable difference between the frequency of events for the 1day annual maximum flow, where there are more events in late winter to early spring in the Lake Tahoe Basin. Perhaps this is an artifact of record length.

The seasonality of events for maximum flows points to the occurrence of runoff due to both winter regional storms and summer convective type events. Although the winter storms do not produce flood as frequently as the summer events, these events have a significant influence on the estimated flood risk.

5.3. Flow variability

The variation of flow characteristics is typically measured by the coefficient of variation (CV) which is the ratio of the standard deviation to the mean of a particular flow distribution. Comparing the gage flow record CV is useful for assessing the similarity in runoff characteristics in the Lake Tahoe Basin.

Comparison of CV is complicated by the influence of record length and drainage area distribution. CV estimates are affected to some extent by sampling error (the error due to limited record length) in the mean and standard deviation. However, these statistics are very stable, and, sampling error would not be expected to affect regional comparison with CV.

CV decreases with drainage area. This occurs because the mean is more highly correlated with drainage area than the standard deviation. Consequently, comparisons between gages should be made for the same range in drainage areas.

The distribution of gage drainage areas corresponds fairly well as, except for relatively large areas for some of the regional gages (gages outside the Lake Tahoe Basin) as is shown in Figure 5.7. Figure 5.8 demonstrates that the larger the gage drainage area the greater the gage record length for the study gages. Despite this record length difference, CV varies regularly as both a function of record length and drainage area as can be seen in figures 5.9 and 5.10. Furthermore, comparison of the CV values for the Lake Tahoe Basin and regional gages shows a strong similarity as a function of drainage area. Consequently, the variability in runoff characteristics for these gages can be considered approximately equivalent.

5.4. Trend Analysis

Traditional flow frequency analysis assumes that the gage records come from a statistically stationary process (i.e., the mean, variance, and other statistical characteristics of the data do not change with time). This assumption can only be useful over a limited period because of climatic variability. However, the expectation is that the climate in the recent past is indicative of future risk over a planning period (perhaps 100 years), and the corresponding flow frequency can be characterized by a stationary process.

The stationarity of stream flow records within the Lake Tahoe Basin was investigated by examining trends in both gage stream flow and flow stage. This investigation was limited by the relatively short gage record length available. The flow trend with time was investigated for the Blackwood gage which has the longest peak flow record in the Lake Tahoe Basin. A standard t-test (e.g., see pg. 20, Draper and Smith. 1966) was performed to determine if the regression slope of annual peak versus time was significantly different from zero (see figure 5.11). Table 5.1 shows that the t-statistic (a function of the difference between the regression slope and zero) is smaller than the critical value. This indicates that the difference between the sample regression slope coefficient and zero is most likely due to random chance; and consequently, a time trend in the data is not likely.

Table 5.1: Time trend analysis hypothesis test for linear regression slope, Blackwood gage 01336660, Lake Tahoe Basin

[1]t regression slope	significance level (α)	[2]$t_{1-\alpha/2,40}$
0.87	0.10	1.68
	0.05	2.02

[1]absolute value [2]two sided t-test critical value, 40 degrees of freedom

Potential trends in flow depth measurements were qualitatively explored by plotting depth versus time at selected gages within the Lake Tahoe basin. This type of plot could potentially reveal some movement of the gage, change in measuring method or perhaps some effect of climatic variability (although the short record lengths available are unlikely to reveal any significant trends). Inspection of figure 5.12 reveals that there are no apparent trends in depth measurements over the period of record. Given this qualitative analysis, and the lack of a trend in the Blackwood gage annual peak flows, the assumption of stationary flow records is reasonable for flow-frequency analysis.

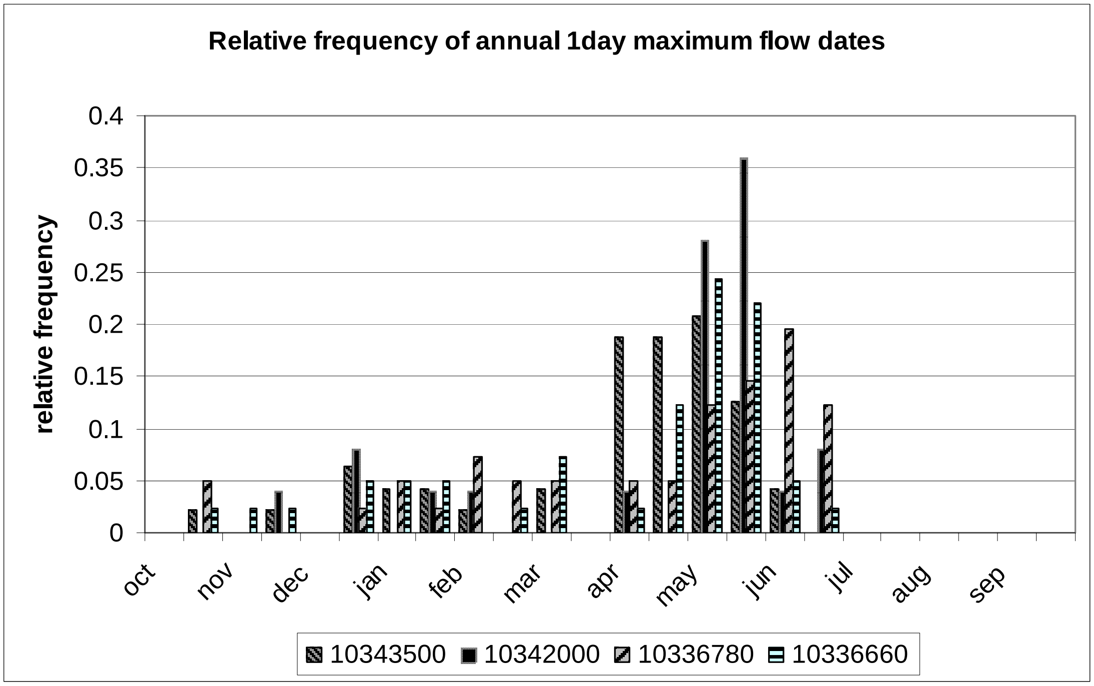

Figure 5.1: 1day annual maximum flow begin dates, Lake Tahoe and near basin Gages (see Table 2.2 USGS gage ID description)

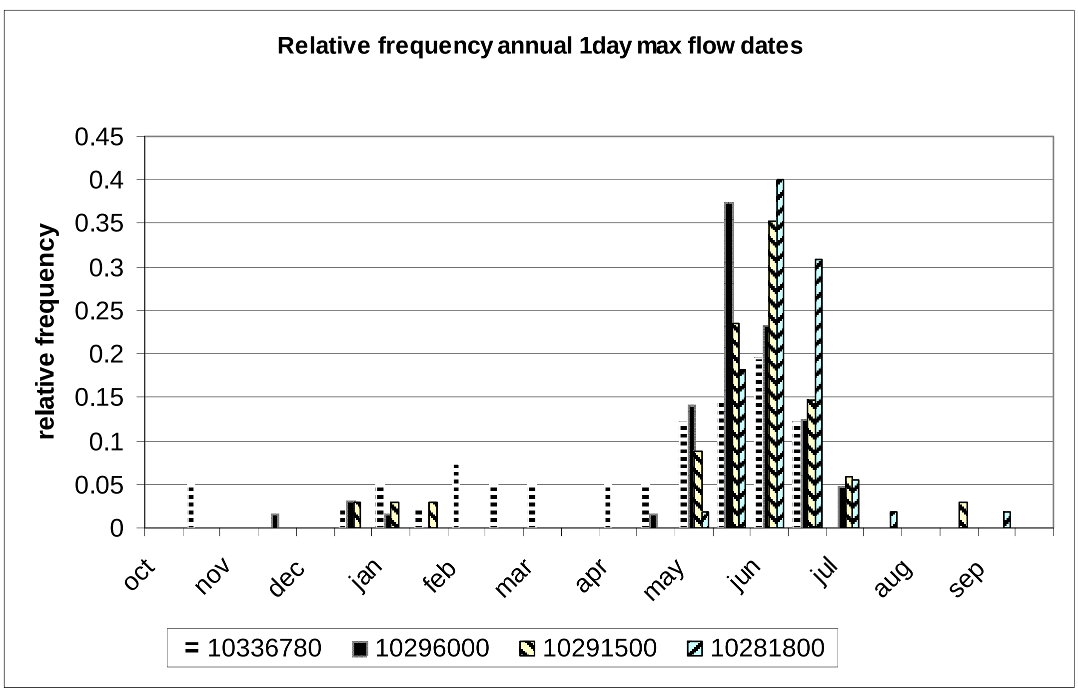

Figure 5.2: 1day annual maximum flow begin dates, Lake Tahoe and regional gages (see Table 2.1 and 2.2 USGS gage ID description)

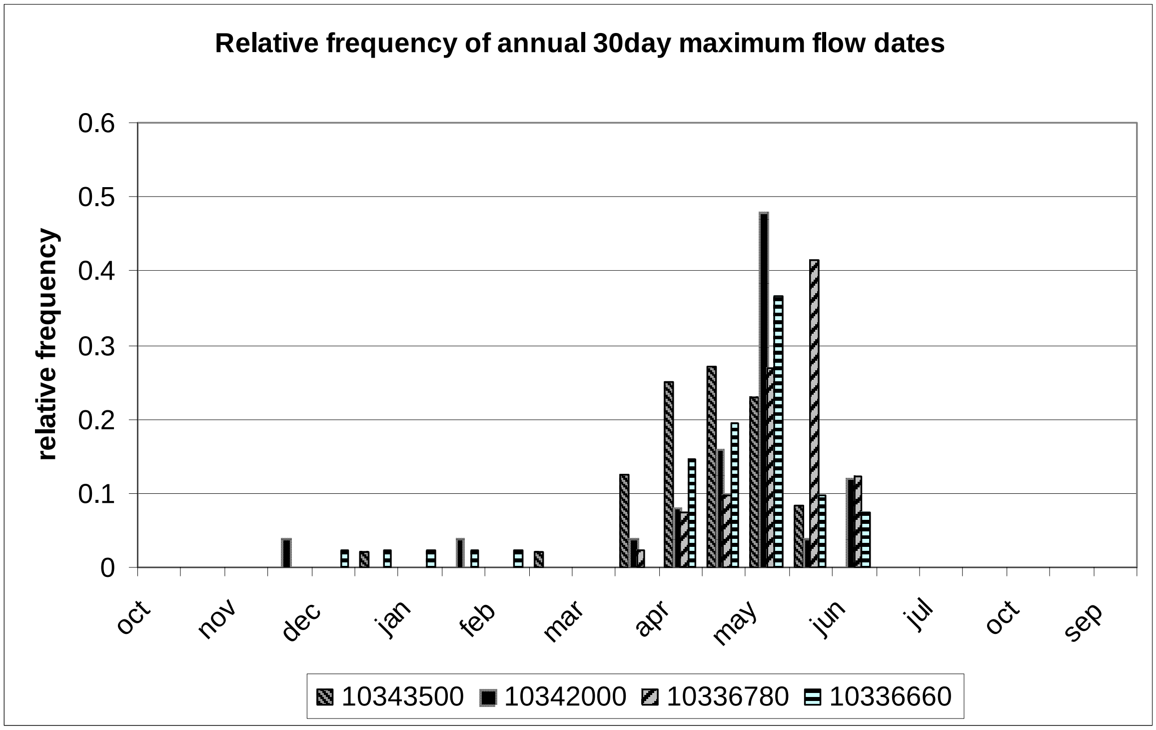

Figure 5.3: 30day annual maximum flow begin dates, Lake Tahoe and near basin Gages (see Table 2.2 USGS gage ID description)

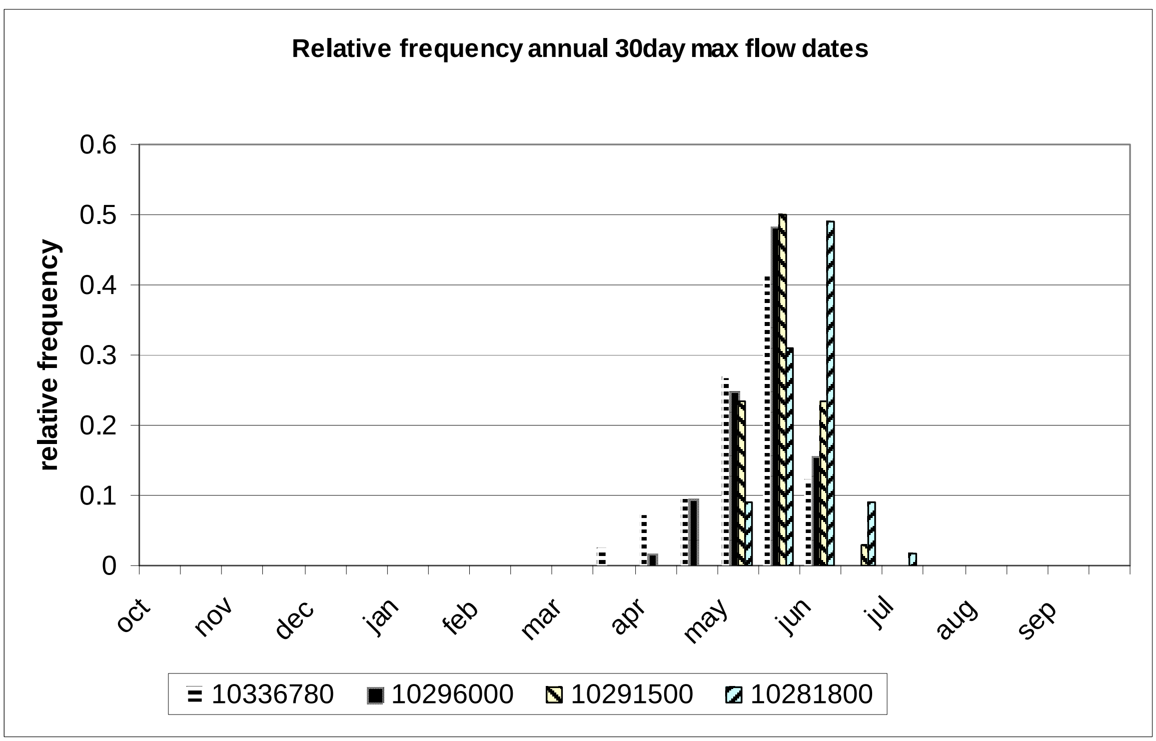

Figure 5.4: 30day annual maximum flow begin dates, Lake Tahoe and regional gages (see Table 2.1 and 2.2 USGS gage ID description)

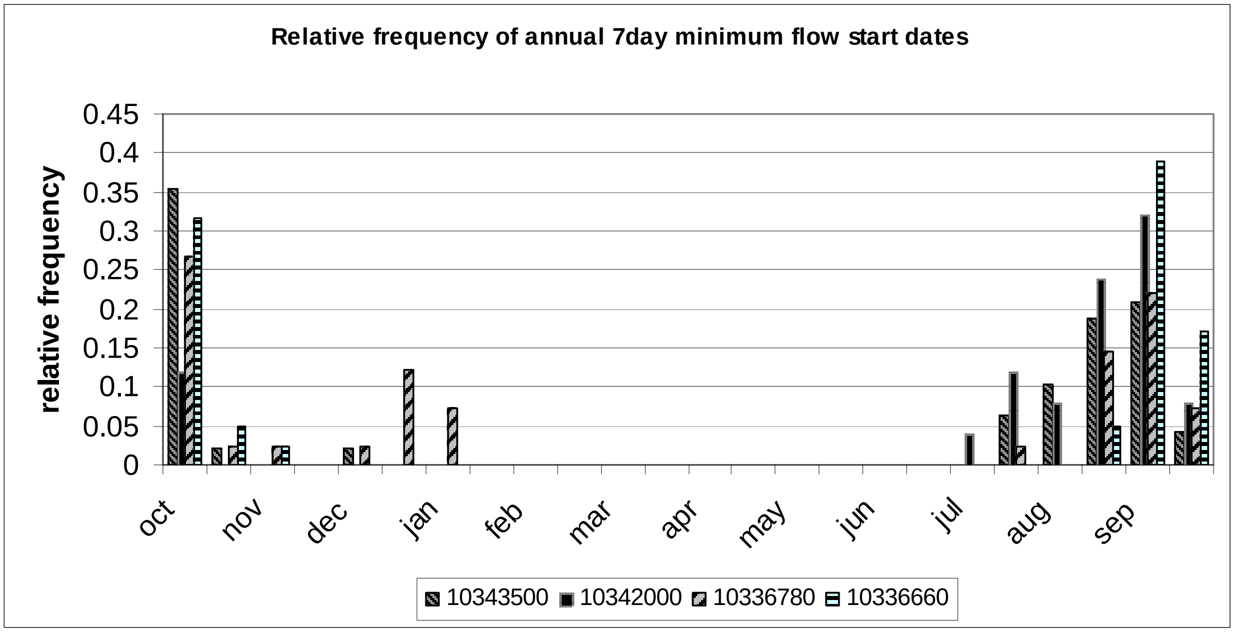

Figure 5.5: 7day annual low flow begin dates, Lake Tahoe and near basin Gages (see Table 2.2 USGS gage ID description)

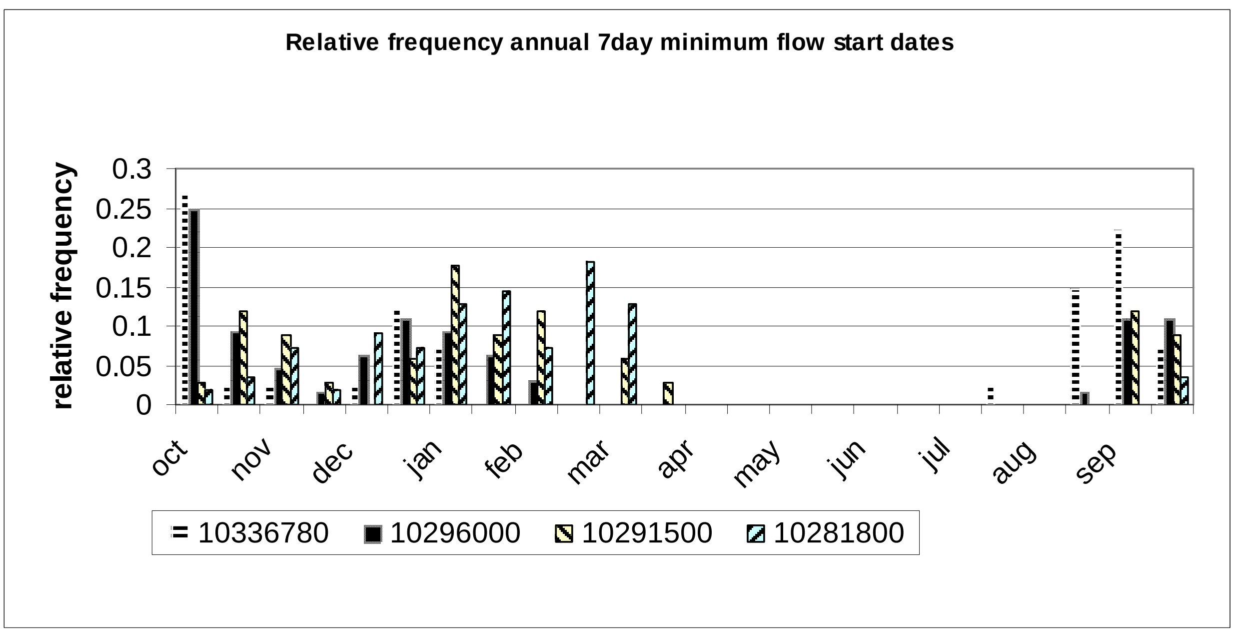

Figure 5.6: 7day annual minimum flow begin dates, Lake Tahoe and regional gages (see Table 2.1 and 2.2 USGS gage ID description)

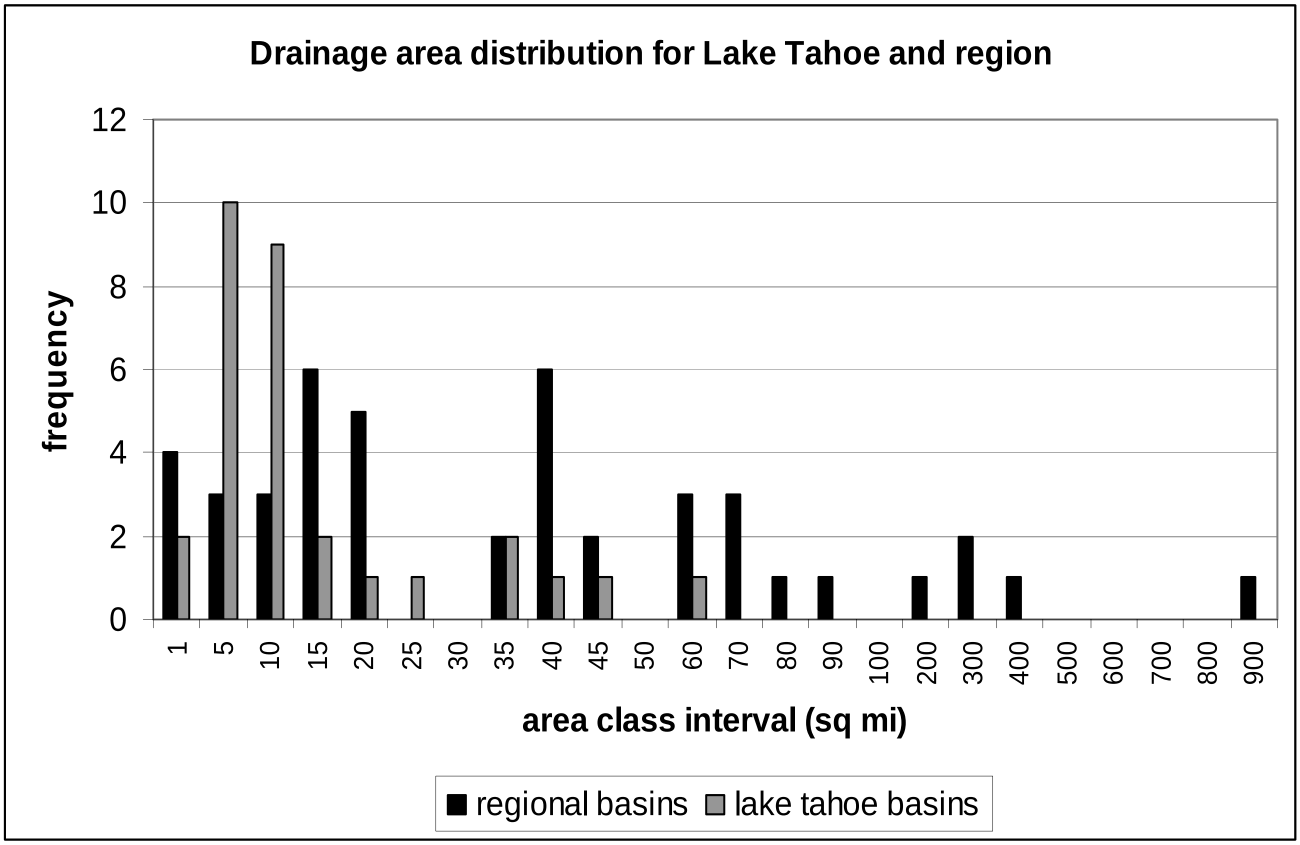

Figure 5.7: Drainage area magnitude distribution for Lake Tahoe and regional gage basins

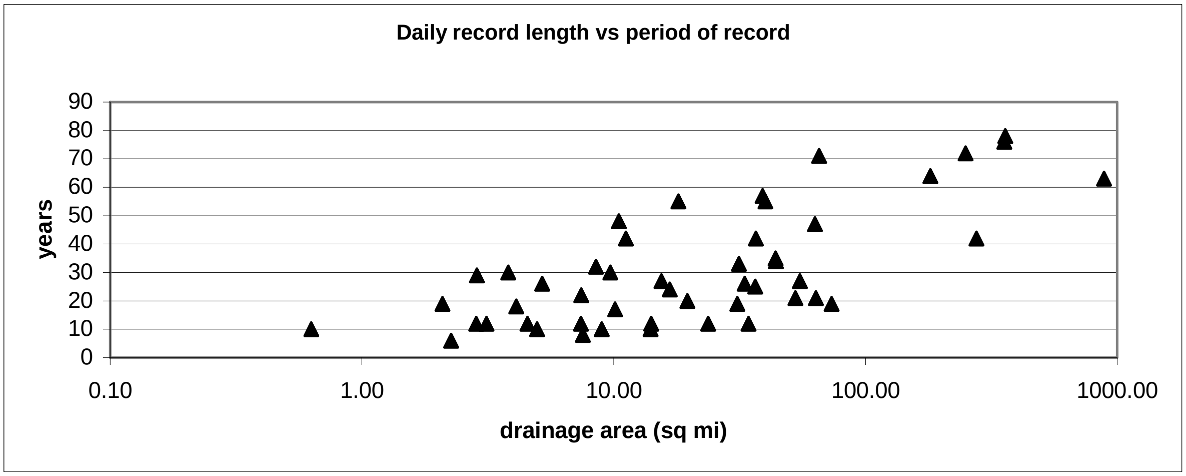

Figure 5.8: Stream gage daily flow period of record versus drainage area all gages

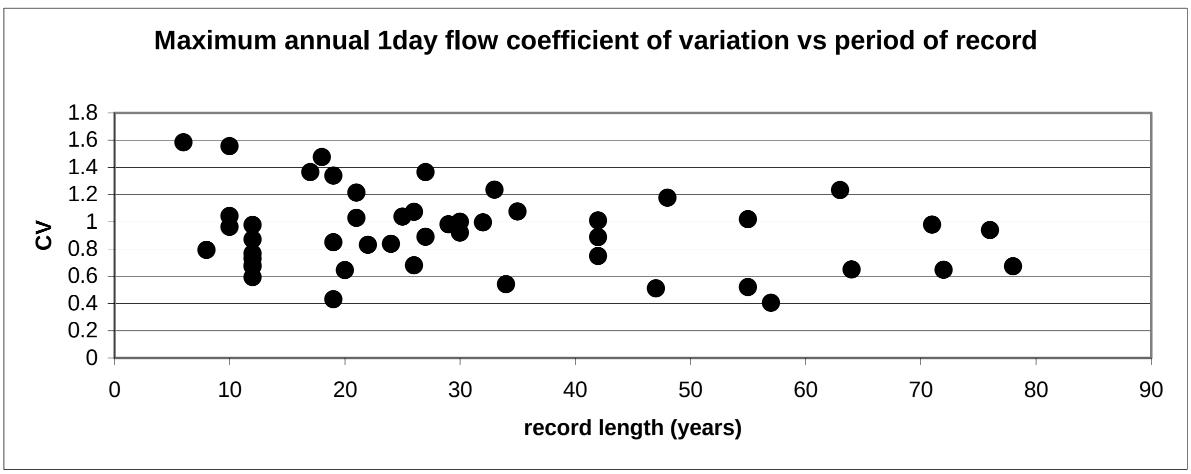

Figure 5.9: Period of record versus coefficient of variation (CV) for 1day annual maximum flow values all gages

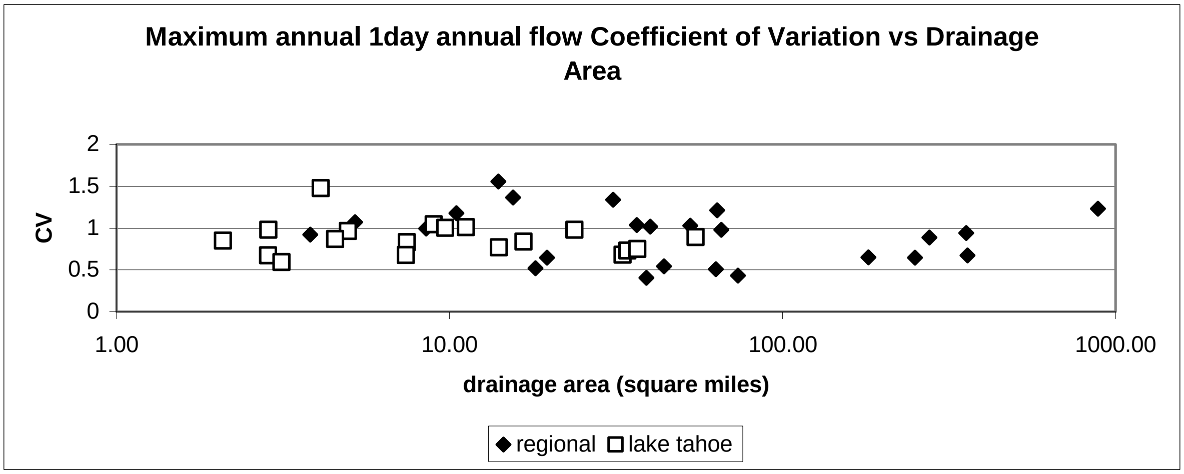

Figure 5.10: Drainage area versus coefficient of variation (CV)

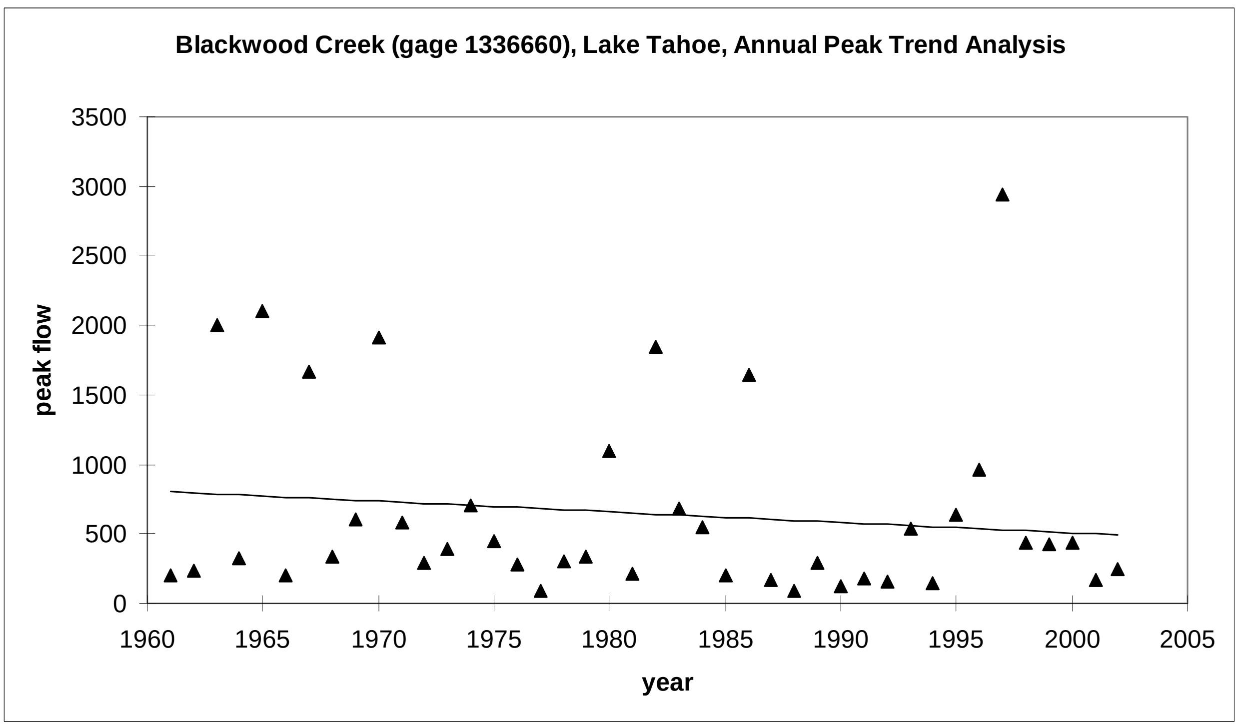

Figure 5.11: Annual peak flow trend analysis, Blackwood gage 01336660, Lake Tahoe Basin

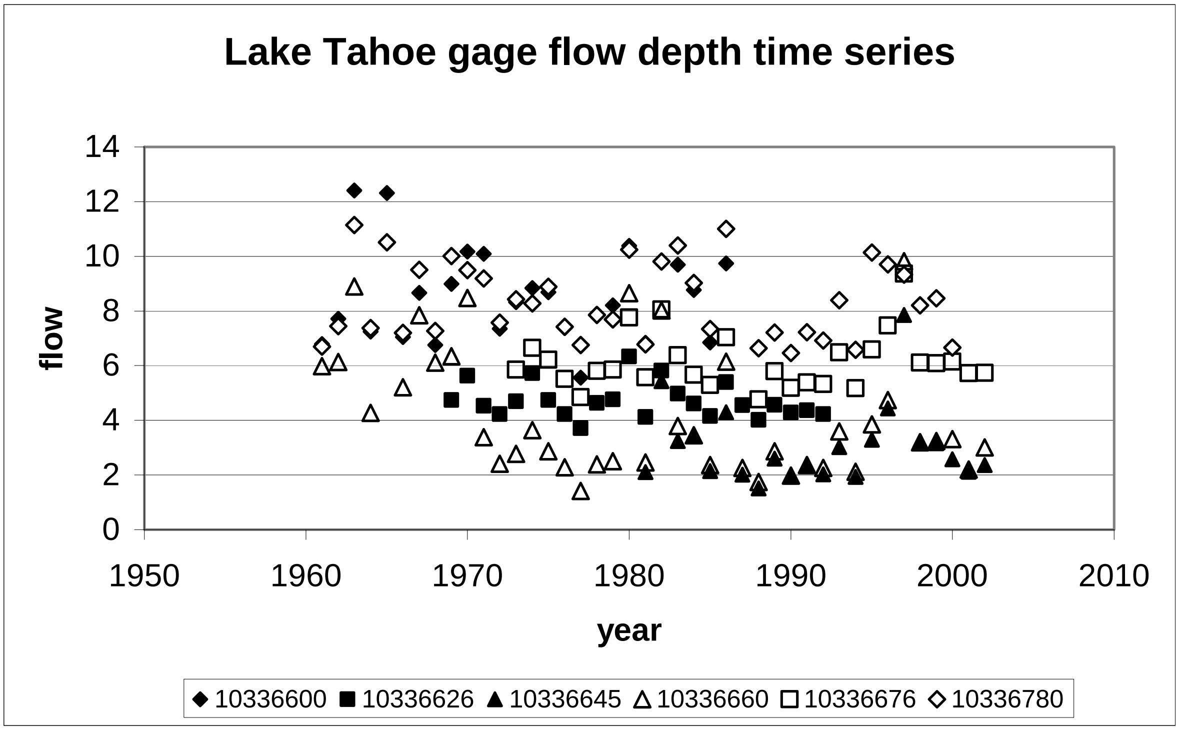

Figure 5.12: Annual maximum depth measurement trends for selected gages in Lake Tahoe Basin

5.5. Flow Duration Analysis

Flow-duration frequency curves provide an overall picture of stream flow characteristics of a watershed. A comparison was made of the flow duration statistics and curve shape to assess the relative similarity between gages used in this study. Table 5.2 compares the gage average median flow (the flow that has a 50% chance of being exceeded daily) as a function of gage location. The difference between median flow per square mile between Lake Tahoe and regional gages does not seem unreasonable given the difference in drainage area (the expectation is that the median flow/square mile would decrease with area). The median flow difference seen between eastern and western slope gages shows the expected decrease given the rain shadow effect caused by the western ridge of the Sierra Mountains.

Table 5.2: Comparison of drainage area and flow for median duration

Drainage Area	average drainage area (sq mi)	[1]average median flow (cfs/sq mi)
Lake Tahoe gages	12.17	0.66
Lake Tahoe [2]west gages	14.48	0.76
Lake Tahoe [2]east gages	9.86	0.57
[3]Region gages	23.22	0.53

[1]Median of flow duration curves
[2]Division of west and east gages judged to be at 120^{o} longitude based on relationship to Sierra Mountain ridge
[3]Gages outside Lake Tahoe Basin

The variation in the shape of flow duration curves in the Lake Tahoe Basin was investigated to see if there is some potential simple scaling relationship that might be used to derive a dimensionless flow duration curve.

Any potential scaling relationship might be difficult to discern because of statistical sampling error. Figure 5.13 demonstrates how differences in record length cause sampling variation in the flow-duration relationship for the Trout Creek gage. As can bee seen, the sampling variation is smaller towards the curve median then at the tails. Consequently, in comparing flow-duration curves, the similarity in curve shape scaled by drainage area might not be as regular as expected because of sampling error.

Figures 5.14-5.16 compare flow duration curves for gages in the same sub-watersheds. The Upper Truckee and Ward Creek gages show similar shapes consistent with increase in gage drainage area (A significant diversion of Upper Truckee flow occurs at Echo Lake, but this does not seem to affect the comparison).. The variation in curves within Trout Creek are not consistent as curves cross. This may be due to sampling error, or perhaps some interaction with the aquifer for gage 10336790 which outlets near the lake.

Scaling of flow duration curves by drainage area was investigated for both western and eastern sloping watersheds with relatively long records. Figure 5.17 show some similarity in the shape of the scaled curves. However, the correspondence between drainage area ratio and flow ratio shown in Table 5.3 varies with exceedance level. The area flow ratios are consistent for the 50% exceedance but not particularly useful otherwise. Apparently, drainage area is not a useful parameter for scaling flow-duration curves.

Table 5.3: Lake Tahoe Basin, area ratio versus ratio of flow at gage to flow at most downstream gage for a given flow duration exceedance for select sub-watersheds

USGS ID	River	area ratio	99%	95%	90%	50%	10%	5%	1%
10336580	UPPER TRUCKEE R AT S UPPER TRUCKEE RD NR MEYERS CA	0.26	0.77	0.44	0.27	0.22	0.42	0.45	0.44
10336600	UP TRUCKEE R NR MEYERS CA	0.60	1.61	1.02	0.63	0.53	0.67	0.72	0.70
103366092	UPPER TRUCKEE R AT HWY 50 ABOVE MEYERS CA	0.62	1.39	0.78	0.60	0.66	0.90	0.91	1.04
10336610	[1]**UPPER TRUCKEE RIVER AT SOUTH LAKE TAHOE CALIF**	**1.0**							
10336674	WARD C BL CONFLUENCE NR TAHOE CITY CA	0.51	0.84	0.81	0.46	0.61	0.74	0.73	0.67
10336675	WARD C AT STANFORD ROCK TRAIL XING NR TAHOE CITY CA	0.92	1.41	1.48	1.15	0.89	1.19	1.12	0.96
10336676	[1]**WARD C AT HWY 89 NR TAHOE PINES CA**	**1.0**							
103367585	Edgewood Creek at Palisade Drive nr Kingsbury, NV	0.56	0.18	0.20	0.21	0.21	0.34	0.39	0.47
10336760	[1]**Edgewood Creek at Stateline, NV**	**1.0**							
10336775	TROUT CREEK AT PIONEER TRAIL NR SOUTH LAKE TAHOE CA	0.65	0.77	0.66	0.58	0.62	0.86	0.75	0.54
10336780	[1]**TROUT C NR TAHOE VALLEY CA**	**1.0**							

[1]The most downstream gage in sub-watershed, ratio of upstream gage drainage area to this gage results in area ratio. The ratios for each frequency exceeded is computed in the same manner.

The standard deviation of the flow duration curve was also investigated as an alternative scaling parameter. As can be seen from figure 5.18, the flow-duration curves seem to scale somewhat better using the standard deviation. However, application of this scaling approach would require some type of regression relationship for predicting the standard deviation in ungaged areas. This requirement does not recommend the method over other regression approaches to regional analysis discussed in the following sections.

In summary, the median characteristics of the flow-duration curves indicate that the flow characteristics of the Lake Tahoe Basin and regional gages are reasonably similar. Furthermore, the flow-duration curve shapes vary regularly throughout the Lake Tahoe Basin. Consequently, the gage data seems to be regionally consistent. Also, the regular variation of the curves makes it reasonable to expect to find useful regional relationships for the basin. Simple scaling probably is not useful for obtaining this relationship.

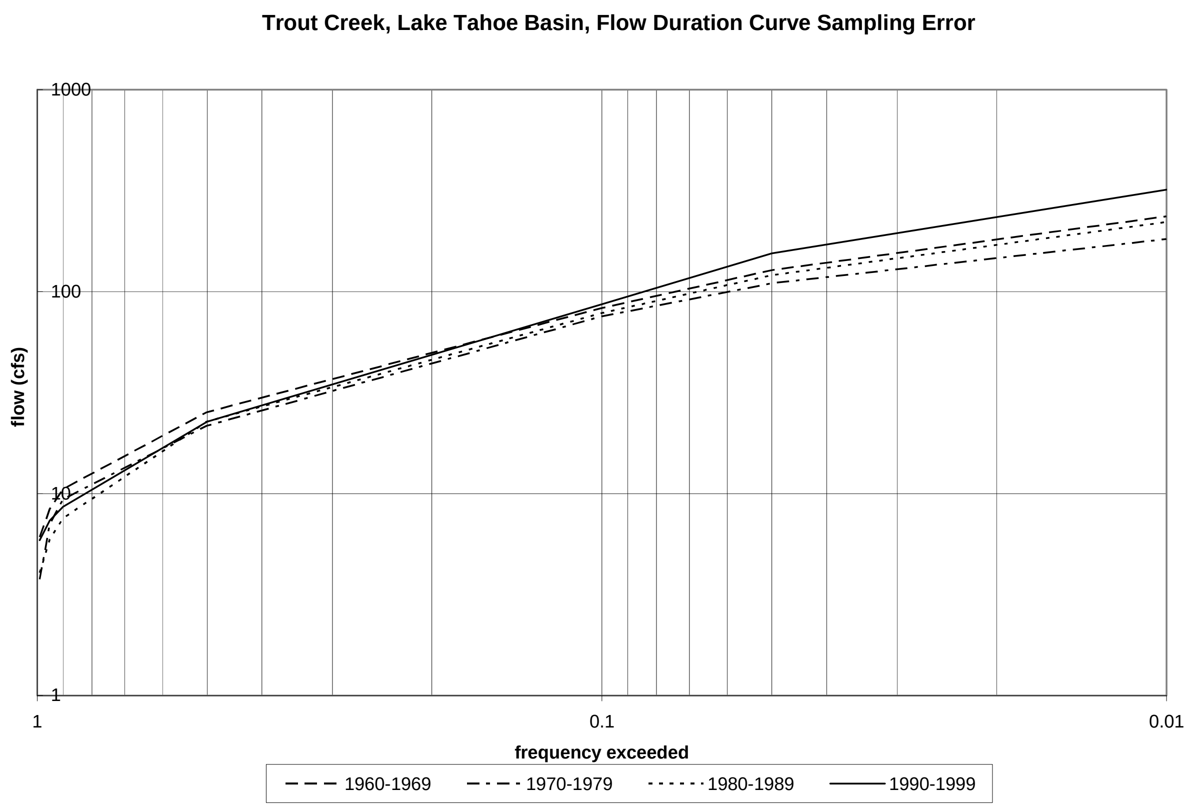

Figure 5.13 Effect of sampling error on estimated flow-duration curve Trout Creek gage 10336780

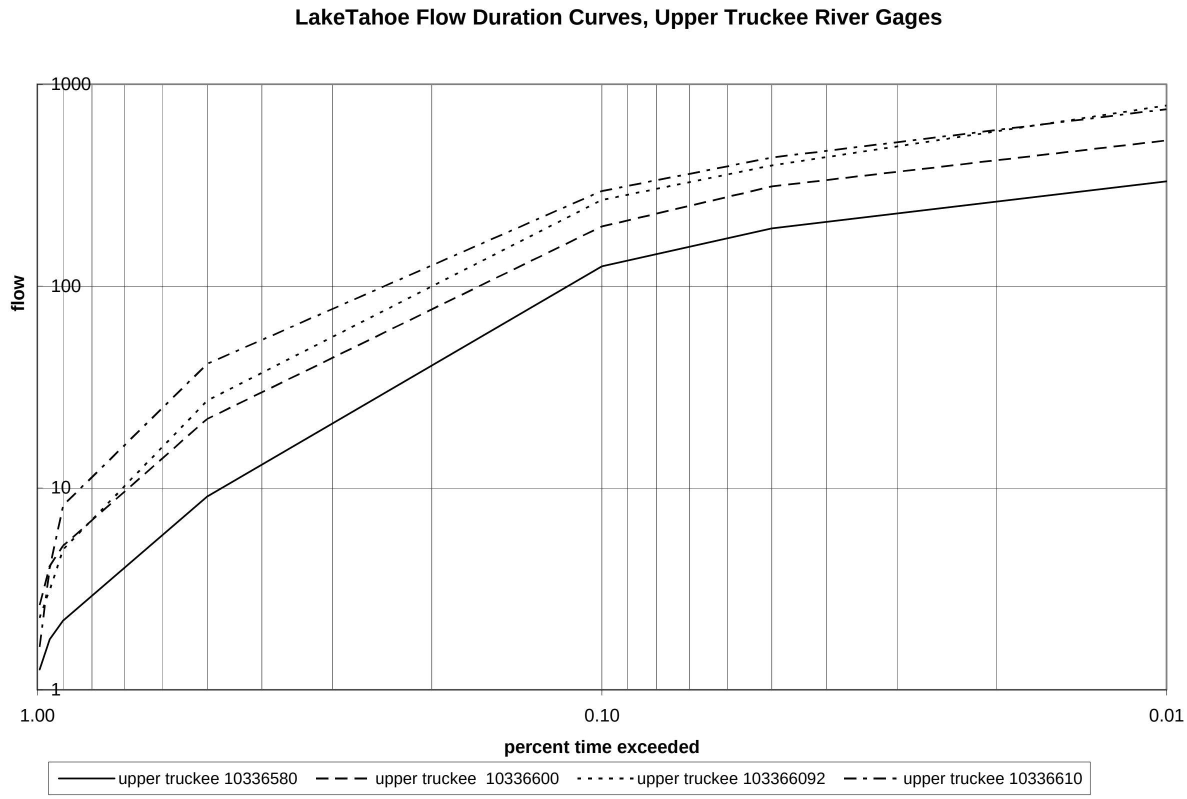

Figure 5.14: Upper Truckee River, flow-duration curves

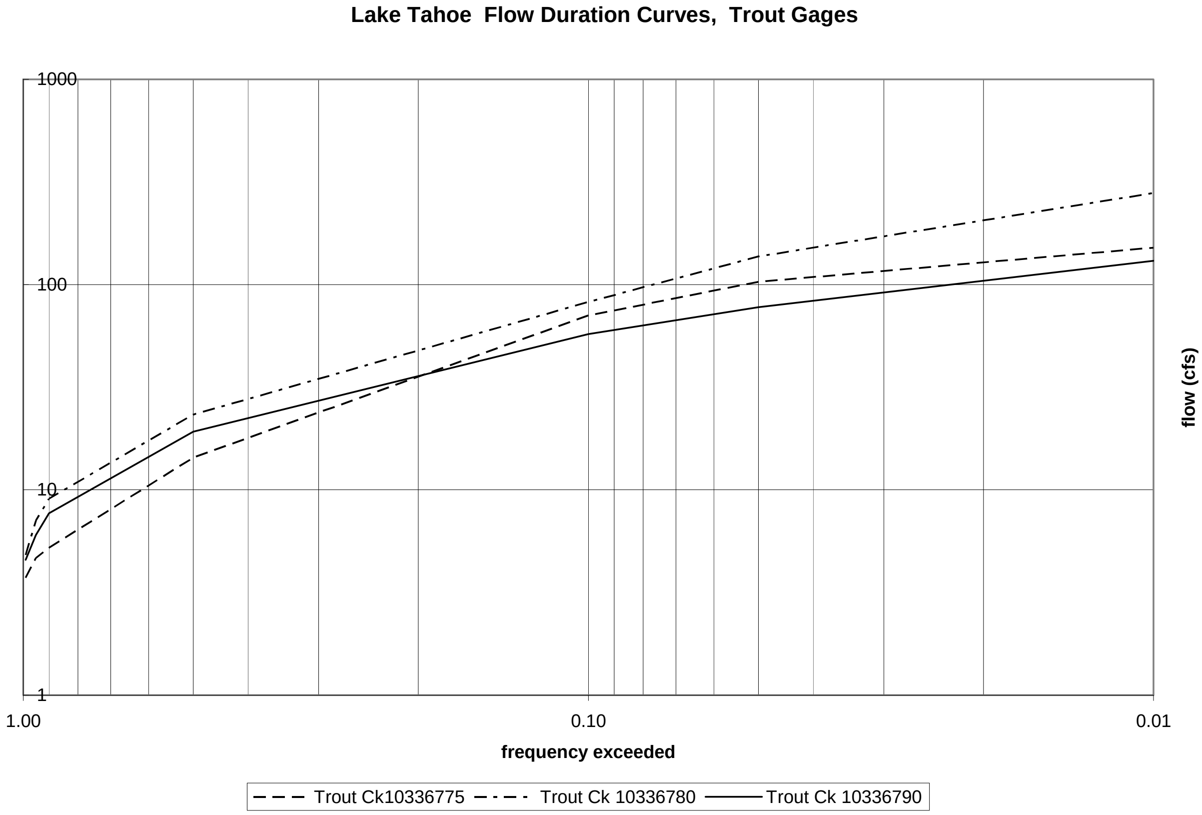

Figure 5.15: Flow duration curves Trout Creek

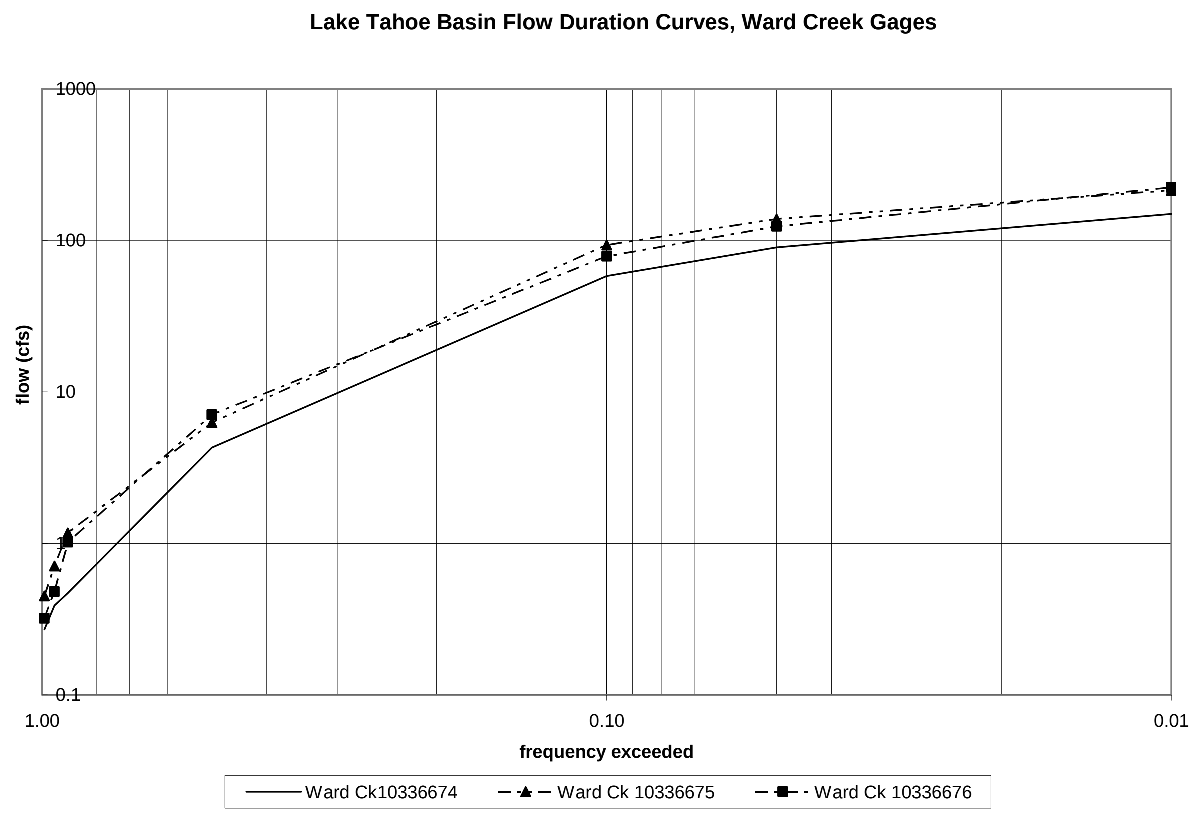

Figure 5.16: Flow duration curves Ward Creek

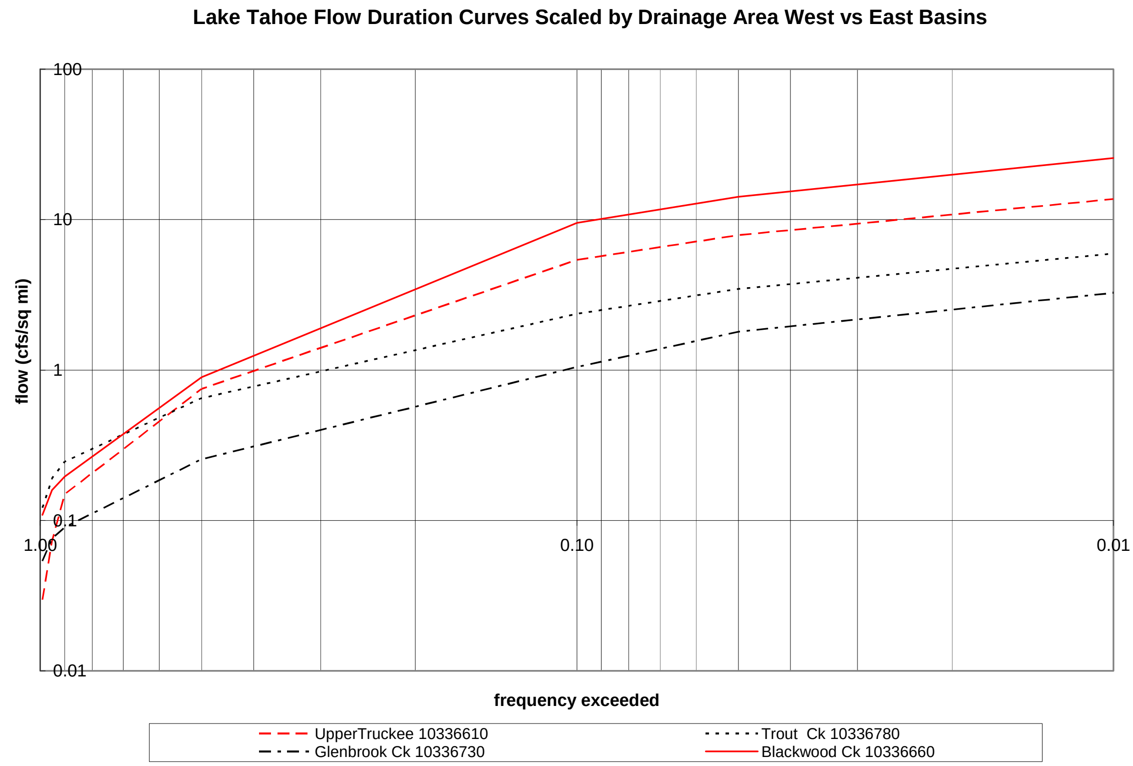

Figure 5.17: Comparison of flow duration curves, scaled by drainage area, western vs. eastern sloping watersheds. relatively longer record lengths

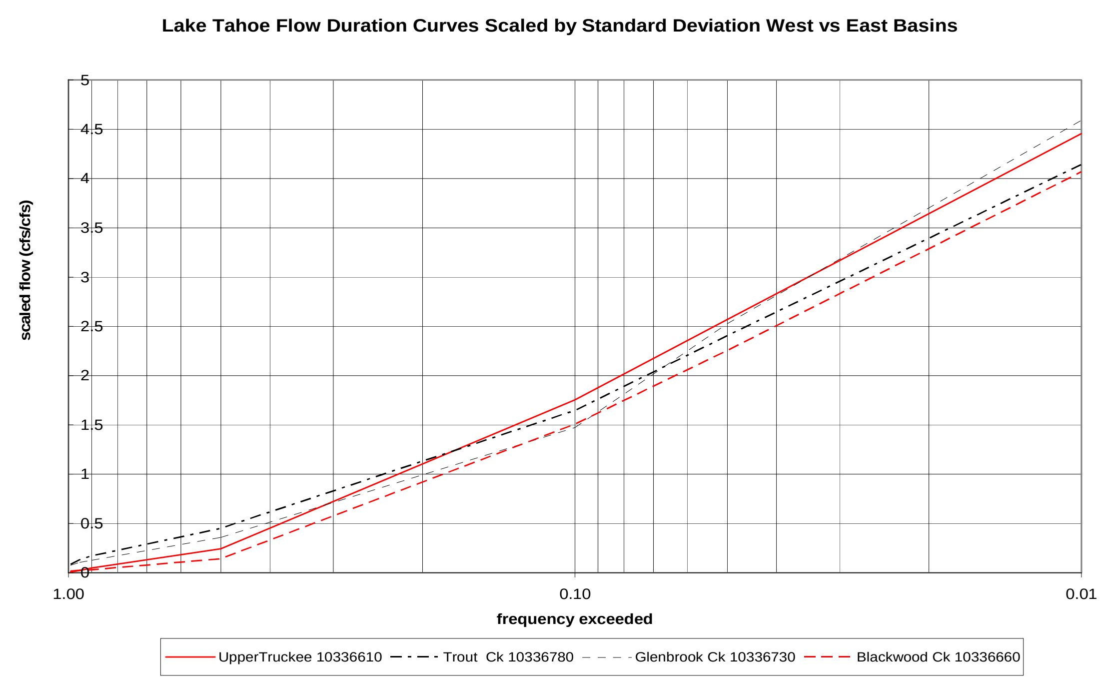

Figure 5.18: Comparison of flow duration curves, scaled by standard deviation, western vs. eastern sloping watersheds. relatively longer record lengths

6. Regional regression estimates for annual peak flow frequency curves

6.1. Introduction

The regional regression equations developed for estimating peak and annual maximum flow frequency curves use only Lake Tahoe Basin gages. Preliminary analysis of the gages described in section 2 revealed that including gages from the entire region did not improve regression performance as measured by standard errors and the R^2, the multiple coefficient of determination, over that obtained by only using Lake Tahoe Basin gages. This preliminary analysis also revealed that using precipitation depth-duration-frequency curves to obtain independent variables (such as the 1% chance 24 hour depth)did not improve regression performance over that obtained using basin average mean annual precipitation.

Given these findings, the regression equations were formulated in the following manner:

- Estimate peak flow frequency curves at gages both within the Lake Tahoe Basin and for the entire region;
- Develop regression equations for the Lake Tahoe gages;
- Perform split sample testing using long-record gages within the entire analysis region to provide additional information on the validity of the regression approach.

Estimating the flow-frequency curves was not straightforward because of the difficulty in assigning a useful exceedance probability to the 1997 event given the limited record lengths of some of the Lake Tahoe basin gages. A historic weighting procedure was used to estimate the exceedance frequency for the 1997 event and obtain flow-frequency estimates for each gage. Section 6.2 describes the application of ordinary, weighted and generalize least squares regression to obtain the regional regression equations for Lake Tahoe Basin (note that weighted least squares is a method that provides a model for the residual errors that can be viewed as intermediary between ordinary and generalized least squares, see section 11, the technical appendix).

Standard statistics are available that measure the statistical significance of a regression equation obtained using ordinary least squares (OLS). As was pointed out in section 4.3, the sampling error in flow-frequency curve estimates requires that generalized least squares (GLS) be applied to obtain the regression relationships. The application of GLS, however, make the determination of statistical significance more difficult. Consequently, split sample testing of the GLS regression using relatively long record length gages in the region was employed to provide an additional measure of the validity of the regression approach as is described in section 7.

6.2. Lake Tahoe basin frequency analysis of peak annual stream flows

A frequency analysis of peak annual stream flows for the Lake Tahoe Basin gages shown in Table 2.6was performed by using the Bulletin 17B guidelines (IACWD, 1982). Only gages with a minimum of 10-years of record were used per the recommendations in the guidelines. In this approach, a log-Pearson III distribution is inferred from the gage data using the standard method of moments.

A major concern resulting from the initial analysis of the data was the plotting position of the 1997 event estimated from the relatively short systematic record length at most of the gages (Note: systematic record length refers to flow peaks recorded as part of the USGS's monitoring program. Alternatively, a historic period, and corresponding historic flows, may also be included in the USGS data base obtained from information on observed high water marks, newspaper accounts, etc.). The 1997 event was a major flood which caused the greatest outflow from Lake Tahoe since at least 1901, or in the past 103 years. However, the event was not the greatest flood of record in three of the 17 gages in the Tahoe Basin that had period of records including the 1997 event (see Table 6.1). Additionally, this event was the largest in 12 of 15 gages sin the region surrounding Lake Tahoe, including a period of record that begins in 1890 at one gage (see Table 6.2).

The problem posed by the 1997 event can be realized by considering the record at the Upper Truckee River at Highway 50 above Meyers, USGS ID 103366092. The 1997 event would have a plotting position estimated exceedance probability of about 1/10 given the 10 year period of record. The concern here is that this is too large an exceedance probability given the regional evidence of the magnitude of this event.

Consequently, the following factors weighed into the treatment of the 1997 event in the frequency analysis:

- The flood distribution is clearly mixed, with floods occurring either due to winter precipitation or spring-summer thunderstorms;
- Even though the 1997 event is almost certainly the largest winter storm since 1901 to occur in the basin, un-recorded spring summer events may have exceeded this event during the period 1901- to present;
- The 1997 event is the most dominant event recorded both within the Lake Tahoe Basin and in the surrounding region since 1901.

The best approach to assigning the appropriate plotting position to the 1997 event would be to perform a mixed distribution analysis. This would be done by combining frequency curves for the annual maximum winter and spring-summer events to obtain an annual frequency curves. The 1997 event would be assigned a "historically weighted" plotting position of about 1/103 corresponding to the observation that it is generally the largest winter event in the past 100-years. This approach would reduce some of the potential error in giving the 1997 event an annual historic weighting at a particular gage where it is reasonably possible that a summer-spring event could have caused a greater event in the period since 1901.

Unfortunately, the USGS data base containing partial duration information on peak flows is not complete, and obtaining both winter and spring-summer events for the gages was not possible. Consequently, the following strategy was used in estimating the peak annual frequency curves for the basin:

- Historic weighting using 103 years of record would be given to the 1997 event when this event is the top ranked event in the period of record. This basically assumes a historic period of record beginning in 1901 corresponding to the period where 1997 was the largest outflow from Lake Tahoe into the Truckee River ;
- Only the systematic period of record was used in analyzing gages where the 1997 event was not top ranked.
- The reasonableness of this approach was checked by comparing the estimated exceedance probability obtained for the 1997 peak with that obtained for the 1day annual maximum obtained using a mixed distribution analysis for the daily flows.

The gage statistics for the systematic period of record, historic period, and the resulting frequency curves are provided in the appendix. No low outliers were found in the data, and, consequently the conditional probability adjustment (see Bulletin 17B, IACWD 1982) was not used to estimate any of the frequency curves. As can be seen from Tables 6.3 and 6.4, there is a significant reduction in estimated flood quantiles obtained by assigning a historic weighting to the 1997 event (e.g., for example, consider the 1% discharge, the average difference is 37%).

The assumptions regarding the historic weighting of the 1997 event was checked by comparing exceedance probabilities estimated for the annual peak and 1day maximum values. As described earlier, the annual peak frequency curves were obtained by giving the 1997 event a plotting position of 1/103 if it was the maximum event in the period of record. However, a mixed distribution analysis was performed for the 1day annual maximums where the 1997 event received the 1/103 historic weighting for the winter distribution. The spring/summer event analysis did not involve any historic weighting. As can be seen for Table 6.5 and figure 6.1, the annual exceedance probabilities correspond reasonably well except for the Logan House gage. Consequently, the historic weighting of the 1997 event most likely provides the most reasonable estimate of the future likelihood that a large event, similar to the 1997, will occur in the future. The estimate of this likelihood obtained from any individual gage is likely to be high or low. However, on the average, the historic weighting probably provides the most reasonable estimate. This average will be reflected in the regression relationship.

Table 6.1: Lake Tahoe Basin gages, observed peak annual flow rank in period of record

USGS ID	Location	[1]Begin	End	[2]first	second	third	fourth	fifth
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	6/4/1991	5/11/2001	1/2/1997	5/16/1996	7/8/1995	5/26/1999	5/31/1993
103366092	Upper Truckee River at Highway 50 above Meyers, CA	5/25/1991	5/15/2001	1/2/1997	5/16/1996	5181993	6251995	5261999
10336610	Upper Truckee River at South Lake Tahoe, CA	1972	2000	1/2/1997	3/8/1986	2161982	5161996	3241998
10336645	General Creek near Meeks Bay, CA	4/30/1981	4/14/2002	1/2/1997	12/20/1981	5161996	3 81986	11111983
10336660	Blackwood Creek near Tahoe City, CA	5/10/1961	4/14/2002	1/1/1997	12/23/1964	1/31/1963	1/21/1970	12/20/1981
10336674	Ward Creek below Confluence near Tahoe City, CA	4/17/1992	5/30/2002	1/1/1997	5/16/1996	5/8/2000	5/31/1993	5/26/1999
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	4/17/1992	5/15/2001	1/1/1997	12/19/1981	11/31/980	5/16/1996	3/8/1986
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	5/16/1973	4/14/2002	1/1/1997	12/19/1981	11/31/980	5/16/1996	3/8/1986
10336730	Glenbrook Creek at Glenbrook, NV	3/3/1972	5/19/2001	1/2/1997	6/7/1998	5/16/1996	5/26/1999	5/14/1975
10336740	Logan House Creek nr Glenbrook, NV	5/10/1984	4/25/2001	1/2/1997	6121998	5251999	5311995	5211996
10336756	Edgewood Creek Tributary near Daggett Pass. NV	4/24/1991	04/2000/00	1/2/1997	5/1999	5 01995	4 02000	4 01996
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	8/14/1991	3/28/2001	8/14/1991	1/2/1997	5/16/1996	3/24/1998	5/121999
103367592	Eagle Rock Creek nr Stateline, NV	2/3/1990	2/13/2000	1/2/1997	3/21/991	3/24/1998	12/12/1995	4/19/1999
10336760	Edgewood Creek at Stateline, NV	5/3/1993	5/30/2001	1/2/1997	3/24/1998	12/12/1995	5/1/1995	5/13/1999
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	6/3/1991	5/24/2000	6/27/1995	5/16/1996	5/28/1999	6/15/1998	1/21/997
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	9/18/1990	5/12/2001	1/2/1997	6/30/1995	5/16/1996	5/28/1999	6/25/1998
10336780	Trout Creek near Tahoe Valley, CA	6/14/1961	2/14/2000	2/1/1963	1/2/1997	3/8/1986	12/24/1964	6/18/1983
10337500	Truckee River at Lake Tahoe	8/11/1901	7/25/2003	1/2/1997	6191969	3131986	12261983	5/2/11996

[1]Beginning period of record
[2]Rank in period of record

Table 6.2: USGS regional gages, observed peak annual flow rank in period of record

USGS ID	Location	[1]Begin	End	[2]first	second	third	fourth	fifth
10293000	E Walker River near Bridgeport, CA	5/22/1923	5/12/2001	1/2/1997	11/20/1950	12/11/1937	12/23/1955	5/16/ 1996
10295500	Lower Walker River near Bridgeport, CA	2/2/1945	5/16/2001	1/2/1997	1/31/1963	5/16/1996	3/8/1986	12/23/1955
10296000	W Walker River below Lower Walker River Near Coleville, CA	12/11/1937	5/16/2001	1/2/1997	11/20/1950	12/11/1937	12/23/1955	5/16/1996
10296500	W Walker River near Coleville, CA	6/1/1903	5/17/2001	1/2/1997	12/11/1937	7/9/1995	7/3/1907	5/16/1996
10299100	Desert Creek near Wellington, NV	8/17/1965	5/23/2000	6/5/1969	6/21/1967	6/0/1975	8/11/1968	1/0/1997
10308800	Bryant Creek near Gardnerville, NV	8/7/1961	4/22/2001	1/2/1997	3/10/1995	1/31/1963	1/13/1980	3/24/1998
10309000	East Fork Carson River near Gardnerville, NV	5/28/1890	5/12/2001	1/3/1997	12/23/1955	2/1/1963	11/21/1950	12/11/1937
10310000	West Fork Carson River at Woodfords, CA	1890	2001	1/1/1997	2/1/1963	12/23/1955	11/20/1950	12/11/1937
10310400	Daggett Creek near Genoa, NV	5/9/1966	7/10/2001	8/5/1971	2/15/1982	1/1/1997	10/26/1982	2/21/1977
10310500	Clear Creek near Carson City, NV	5/6/1948	11/29/2000	1/2/1997	1/31/1963	2/20/1968	12/23/1955	3/16/1967
10311000	Carson River near Carson City, NV	5/12/1939	5/12/2001	1/3/1997	12/24/1955	2/1/1963	11/22/1950	2/18/1986
10311200	Ash Canyon Creek near Carson City, NV	10/1/1976	10/31/2000	1/2/1997	3/24/1998	2/17/1986	5/16/1996	2/14/2000
10311450	Brunswick Canyon near New Empire, NV	8/2/1966	2000	3/11/1995	2/19/1986	7/23/1984	1/2/1997	8/14/1998
10343500	Sagehen Creek near Truckee, CA	4/22/1954	4/14/2002	1/1/1997	2/1/1963	12/23/1964	12/23/1955	3/8/1986

[1]Beginning period of record
[2]Rank in period of record

Table 6.3: Lake Tahoe Basin Stream Gages log-Pearson III estimated annual peak quantiles (50%, 20%, 10%, 4%, 2%, 1%, 0.2%),systematic record vs. estimate with historic period 1997 event

USGS ID	Description	years	[3]50	20	10	4	2	1	0.2
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	[1]11	396.3	758.6	1128.6	1804.9	2508.4	3432.9	6826.8
		[2]103	372.6	588.0	755.4	995.8	1196.5	1416.2	2012.4
10336600	Upper Truckee River near Meyers, CA	26	696.7	1234.7	1668.9	2305.0	2842.2	3433.8	5043.7
103366092	Upper Truckee River at Highway 50 above Meyers, CA	25	842.9	1889.5	2977.7	4961.1	6997.8	9627.4	18891.1
			760.7	1415.7	1961.9	2782.0	3488.6	4278.2	6474.8
10336610	[1]Upper Truckee River at South Lake Tahoe, CA	24	743.2	1549.8	2330.3	3666.3	4963.6	6563.3	11789.1
			721.7	1380.3	1946.9	2820.3	3590.6	4467.9	6983.5
10336626	Taylor Creek near Camp Richardson, CA	11	282.0	563.7	847.1	1355.1	1872.4	2538.6	4893.0
10336635	Lake Tahoe Tributary near Meeks Bay	22	7.6	16.1	24.9	41.0	57.6	79.4	157.5
		103							
10336645	General Creek near Meeks Bay, CA	42	210.6	403.3	566.6	814.5	1029.7	1271.7	1950.0
		103	201.0	369.4	506.9	709.5	881.2	1070.4	1584.9
10336660	Blackwood Creek near Tahoe City, CA	11	392.9	882.3	1400.4	2362.7	3369.1	4689.7	9476.4
		103	384.4	838.0	1304.6	2149.5	3013.5	4126.2	8036.8
10336674	Ward Creek below Confluence near Tahoe City, CA	10	218.2	447.4	660.3	1010.6	1338.2	1729.6	2940.7
		103	205.7	333.1	413.4	507.1	571.0	629.8	750.2
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	30	327.9	775.8	1265.6	2199.2	3196.5	4526.7	9472.1
		103	296.9	541.2	730.4	994.9	1208.0	1432.9	2002.7
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	12	290.2	689.5	1104.6	1852.1	2607.0	3564.6	6821.3
		103	280.0	626.4	963.0	1533.8	2079.8	2742.3	4835.5
10336693	Wood Creek near Crystal Bay, NV	18	17.6	29.7	36.9	44.7	49.5	53.7	61.3
10336730	Glenbrook Creek at Glenbrook, NV	18	9.1	26.8	49.4	98.2	156.2	240.3	597.7
		103	8.5	21.0	34.2	58.0	81.9	112.1	213.6
10336740	Logan House Creek nr Glenbrook, NV	10	3.8	7.9	11.0	15.2	18.4	21.6	28.9
		103	3.3	6.5	8.9	12.2	14.6	17.1	22.7
10336756	Edgewood Creek Tributary near Daggett Pass. NV	10	2.4	6.1	8.7	11.5	13.2	14.6	16.8
			1.9	5.2	7.7	11.0	13.3	15.4	19.6
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	12	11.0	28.0	44.0	74.0	100.0	140.0	240.0
		103							
103367592	Eagle Rock Creek nr Stateline, NV	40	1.6	2.4	3.0	3.9	4.5	10.0	10.0
		103	1.5	2.1	2.4	2.9	3.2	3.4	4.0
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	11	77.1	119.9	144.3	170.2	186.4	200.2	225.6
		103							
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	11	98.4	230.4	368.4	619.8	876.7	1206.3	2351.3
			87.2	182.2	273.0	426.4	573.4	752.6	1326.8
10336780	Trout Creek near Tahoe Valley, CA	11	144.8	276.6	387.7	555.6	700.9	863.6	1317.4
		103	139.1	258.3	356.7	502.7	627.1	764.9	1142.5
	average difference (systematic vs. historic)		**0.08**	**0.17**	**0.22**	**0.28**	**0.32**	**0.37**	**0.41**

[1]Systematic period of record (gage record), [2]historic period assigned to 1997 event [3]Percent chance exceedance

Table 6.4: Lake Tahoe Basin Stream Gages log-Pearson III estimated annual peak quantiles (99%, 95%, 90%, 80%),systematic record vs. estimate with historic period 1997 event

USGS ID	Description	years	[1]99	95	90	80
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	11	128.0	163.0	190.6	237.2
		103	122.7	166.2	196.8	243.1
10336600	Upper Truckee River near Meyers, CA	26	147.2	231.2	294.4	395.2
103366092	Upper Truckee River at Highway 50 above Meyers, CA	25	135.8	218.5	287.2	407.3
			139.6	228.6	297.7	410.4
10336610	[1]Upper Truckee River at South Lake Tahoe, CA	24	131.1	208.7	271.2	377.7
		103	128.1	210.5	275.3	382.0
10336626	Taylor Creek near Camp Richardson, CA	11	71.2	98.8	120.5	157.1
10336635	Lake Tahoe Tributary near Meeks Bay	22	1.6	2.4	3.0	4.0
		103				
10336645	General Creek near Meeks Bay, CA	42	35.1	59.3	78.4	110.0
		103	36.7	60.5	79.0	109.0
10336660	Blackwood Creek near Tahoe City, CA	11	67.7	105.7	137.2	192.3
		103	68.7	106.9	138.1	192.1
10336674	Ward Creek below Confluence near Tahoe City, CA	10	35.7	59.1	78.0	110.1
		103	32.1	60.2	81.7	115.2
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	30	49.1	79.9	105.9	152.4
		103	46.7	82.7	111.0	157.1
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	12	33.6	61.0	84.8	127.9
		103	34.0	62.0	85.8	128.0
10336693	Wood Creek near Crystal Bay, NV	18	1.71	3.91	5.80	8.9
10336730	Glenbrook Creek at Glenbrook, NV	18	0.80	1.5	2.2	3.4
		103	0.79	1.5	2.2	3.5
10336740	Logan House Creek nr Glenbrook, NV	10	0.26	0.6	1.0	1.6
		103	0.28	0.6	0.9	1.5
10336756	Edgewood Creek Tributary near Daggett Pass. NV	10	0.02	0.1	0.2	0.6
		103	0.02	0.1	0.2	0.5
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	12	0.84	1.8	2.7	4.4
103367592	Eagle Rock Creek nr Stateline, NV	40	0.41	0.61	0.76	0.97
		103	0.42	0.63	0.77	0.98
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	11	11.4	22.4	30.8	43.7
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	11	12.9	22.3	30.3	44.7
			14.5	23.7	31.1	43.8
10336780	Trout Creek near Tahoe Valley, CA	11	24.1	40.8	54.0	75.8
		103	24.7	41.1	53.8	74.6
	average difference		**-0.01**	**-0.03**	**-0.01**	**0.01**

[1]Systematic period of record (gage record), [2]historic period assigned to 1997 event [3]Percent chance exceedance

Table 6.5: Comparison of peak and maximum annual 1day flow exceedance probabilities

Watershed	USGS ID	[1]prob peak	prob 1day
UPPER TRUCKEE	10336580	0.002	0.003
UPPER TRUCKEE	103366092	0.005	0.025
UPPER TRUCKEE	10336610	0.005	0.015
GENERAL	10336645	0.028	0.025
BLACKWOOD	10336660	0.021	0.019
WARD	10336674	0.001	0.001
WARD	10336675	0.001	0.001
WARD	10336676	0.012	0.007
GLENBROOK	10336730	0.006	0.009
LOGAN HOUSE	10336740	0.372	0.060
EDGEWOOD	103367585	0.136	0.004
EAGLE ROCK	103367592	0.002	0.007
TROUT	10336770	0.363	0.200
TROUT	10336775	0.025	0.018
TROUT	10336780	0.033	0.026

[1]Peak probabilities computed from annual events historic weighting 1997, 1day probabilities computed from mixed distribution, 1997 event historic weighting for winter events

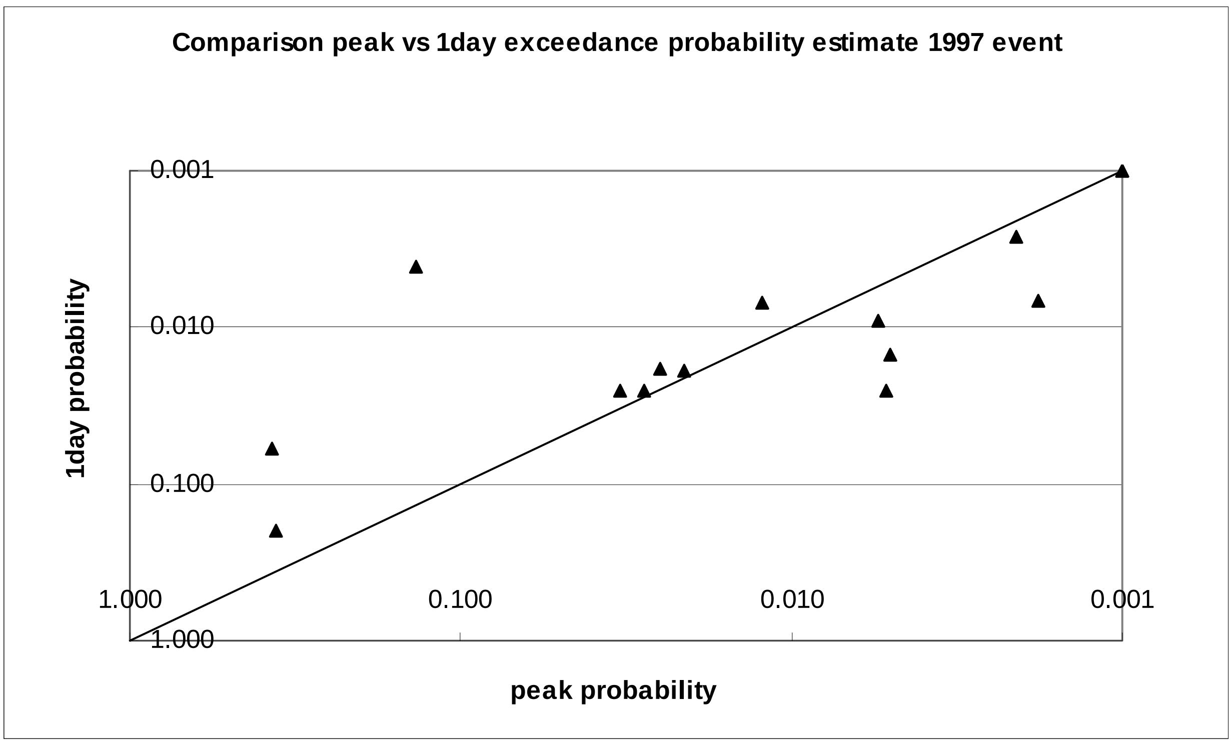

Figure 6.1: Comparison of peak and annual maximum 1day flow exceedance probability estimated for 1997 events (peak exceedance from annual analysis, 1day from mixed distribution analysis).

6.3. Lake Tahoe Basin peak annual stream flow regression results

Peak annual regression relationships were developed for a linear relationship of the form

$$\log_{10}\left(Q_p\right) = b_0 + b_1\log_{10}\left(X_1\right) + b_2\log_{10}\left(X_2\right) + \ldots e \tag{6.1}$$

where Qp is the quantile for exceedance probability p (e.g., the 1% chance exceedance flow), the X_i are the independent variables (e.g., drainage area) and the b_i are regression coefficients and e is residual regression estimation error (refer to section 11, the technical appendix for a further discussion).

The regression equations were developed using ordinary, weighted and generalized least squares (OLS, WLS and GLS). The weighting of each estimate of Q_p in WLS and GLS is proportional to the accuracy of the estimate. This estimation accuracy is inversely proportional to the gage record length. Additionally, the covariance between peak flows observed at each gage influences the importance of Q_p estimated at each gage when applying GLS.

The application of WLS and GLS was not straightforward because historic information was used in estimating Q_p and the high inter-gage covariance of peak flows in the Lake Tahoe Basin. The appropriate weighting of observations in the regression derivation for Q_p values obtained using historic information was obtained by computing an effective record length. The effects of covariance were managed by smoothing the inter-gage covariance estimates. For further details see section 11, the technical appendix.

The comparative study performed to estimate useful regional regressions had the following goals:

- Identify the combination of independent parameters that provide best prediction accuracy while at the same time being parsimonious in parameters (i.e., using as few independent parameters as necessary to explain the variance of the dependent variable).
- Select a consistent set of independent variables to facilitate the practical use of the regression equations. For example, mean annual snowfall and mean annual precipitation (MAP)were used as independent variables in the regression study. If MAP was included in the best regression in most cases, but mean annual snowfall was marginally superior to MAP, then the regression using MAP was selected.
- Compare OLS, WLS and GLS for informational purposes. The GLS approach uses the best model of regression errors to develop the regression equation. However, this approach is not typically used; and comparing the various regression techniques provides information on how different models for regression error affects results.

Regression selection was based on “average prediction error”, which is a measure of regression prediction error similar to that of the standard error (see the technical appendix for further discussion). The correlation and unequal variance of regression errors due to the sampling error in the estimated quantiles and correlation of annual peaks makes more standard measures of regression accuracy less informative than in a standard OLS application. The overall consistency of the data, the identification of outliers or influential values was investigated by computing a leverage measure (for a further discussion of leverage refer to section 11, the technical appendix). Standard measures of regression performance, R^2 (the adjusted multiple coefficient of determination) and the standard error are provided for comparison. In general, the various measures of prediction error provide about the same picture of performance for the regressions investigated.

The strategy for investigating parameter combinations was to test all possible regression for the 0.01, 0.50, and 0.95 exceedance probability quantiles. The results for these quantiles were then used to limit the combinations of parameters investigated for other quantiles. This had the advantage of both providing consistent but accurate results, as well as making the development of the equations more efficient.

Investigation of the data leverage did not reveal any outlying gages consistently over all the regressions. Tables 6.6-6.10 provides a summary of the various combination of independent parameters used in the regression prediction. In developing the regressions, the gage longitude was added to the parameter set to investigate the value of a non-GIS developed parameter on the regression equations. Investigation of these results show that, generally, the combination of drainage area (square miles)and basin average MAP (inches) for quantiles greater than or equal to 0.5 exceedance probability, and, drainage area, basin average elevation (feet msl) and basin average mean annual snowfall (inches) for quantiles less than 0.2 exceedance probability meet the combined goals of average prediction accuracy, parsimony and applicability. Drainage area, basin average MAP and elevation performed best for exceedance probability 0.2. Table 6.11 summarizes the selected equations. Also, presented are the second best performing equations for exceedance probabilities less than 0.2. The recommendation is to use the regression MAP* equations because: 1) the MAP parameter is more easily obtained; 2) regression prediction accuracy does not suffer greatly; and, 3) more consistent results will be obtained in applying the equations at the limits of regression equation applicability.

*Recommendation revised - see Final Summary Report

Figures 6.2-6.4 provide a comparison of the 1%, 50%, and 95% log-Pearson III estimated and ordinary and generalized least regression predicted quantiles. Notice that the estimates do not differ greatly, which is expected. The value in the GLS approach is in providing a more appropriate measure of regression performance than would be obtained from an OLS approach. These methods generally do not result in greatly differing regression equations.

A bothersome aspect of the regression application is the inclusion of the very relatively large area Upper Truckee River (54.9 sq mi, USGS ID 10336610) and Trout Creek (36.7 sq mi, 10336780) gages in the data set. Figure 6.1 shows this potential problem where the Upper Truckee 1% estimate is about 5000 cfs and the regression prediction is about 7,000 cfs. Although the leverage statistics indicated that these gages do not exert undue influence on the regression, the hydrology of the area draining two these gages is different than the rest of the gages considered. Consequently, these sensitivity of results was examined be obtaining regression estimates without these two gages. Table 6.12 shows that the regressions with the full data set result in a 15% greater average prediction than for the regressions not using the larger area gages. Given the difficulty in estimating the 1% with the relatively short Lake Tahoe gage record lengths, this is perhaps not a large difference. The difference at the 50% estimate is a reasonable small 5%.

In conclusion, the regression equation provide estimates of the quantiles with an expected prediction accuracy shown in Table 6.11. The application regression application should be limited to the range of independent parameters investigated, namely where drainage areas:

- are greater than 0.1 square miles;
- have a significant portion of drainage area above elevation 7000 feet;
- where land use is predominately open (e.g., forest and pasture)
- are not located within the broad flood plain below Meyers at highway 50;
- open (not urban).

Table 6.6: Lake Tahoe Regression parameters, error measures for 0.002, 0.01, annual peak quantiles

	constant	[1]area	[2]map	[3]snow	[4]elevation	[5]longitude	[6]se	[7]R^2	[8]avp
0.20%									
	constant	area		precip					
ols	-3.3623	1.0716		3.2103			0.37	0.85	0.157
wls	-3.7191	1.1292		3.3706			0.38	0.85	0.115
gls	-3.8991	1.0957		3.4176			0.42	0.81	0.104
	constant	area	elevation	precip					
ols	44.2696	1.1865	-11.9947	2.5352			0.24	0.94	0.072
wls	39.4097	1.2062	-10.8591	2.7733			0.25	0.93	0.040
gls	33.5078	1.1884	-9.3726	2.8118			0.29	0.91	0.041
	constant	area	elevation		snow				
ols	55.0736	1.065	-14.8822		1.9693		0.21	0.95	0.051
wls	53.634	0.9793	-14.7291		2.344		0.22	0.95	0.018
gls	51.4905	1.0048	-14.1498		2.282		0.22	0.95	0.025
1%									
	constant	area							
ols	1.4723	1.36					0.46	0.76	0.231
wls	1.4402	1.3873					0.46	0.76	0.206
gls	1.4056	1.3982					0.46	0.75	0.220
	constant	area	elevation						
ols	50.0654	1.4092	-12.5121				0.36	0.85	0.148
wls	49.66	1.4135	-12.4078				0.36	0.85	0.123
gls	49.9968	1.4398	-12.495				0.36	0.85	0.141
	constant	area		precip					
ols	-3.6202	1.0309		3.2799			0.30	0.90	0.103
wls	-4.012	1.0745		3.4747			0.31	0.89	0.075
gls	-4.1473	1.0577		3.5006			0.34	0.87	0.068
	constant	area			snow				
ols	-3.0574	0.9564			2.0522		0.35	0.86	0.143
wls	-3.2732	0.9693			2.1305		0.35	0.85	0.122
gls	-3.4556	0.9669			2.1829		0.36	0.85	0.126
	constant	area	elevation	precip					
ols	33.3801	1.1202	-9.3174	2.7555			0.21	0.95	0.053
wls	29.9306	1.1339	-8.5508	3.0177			0.22	0.95	0.030
gls	24.8478	1.1256	-7.2637	3.0325			0.24	0.93	0.033
	constant	area	elevation		snow				
ols	45.3458	1.0071	-12.4584		2.0438		0.18	0.96	0.040
wls	46.0032	0.9139	-12.8429		2.4249		0.19	0.96	0.015
gls	44.5481	0.9463	-12.4502		2.3831		0.19	0.96	0.021
	constant	area				long			
ols	-2241.34	1.239				1078.695	0.25	0.93	0.073
wls	-2321.22	1.2879				1117.076	0.26	0.92	0.049
gls	-2186.7	1.2941				1052.337	0.29	0.91	0.048

[1]drainage area (square miles), [2]mean annual precipitation (inches), [3]mean annual maximum snow fall (inches), [4]elevation (feet msl) [5]longitude (absolute decimal degrees), [6]standard error ($\log_{10}$), [7]multiple coefficient of determination (adjusted) R^2 ($\log_{10}$), [8]average prediction error ($\log_{10}$)

Table 6.7: Lake Tahoe Regression parameters, error measures for 0.02, 0.04, 0.1annual peak quantiles

	constant	[1]area	[2]map	[3]snow	[4]elevation	[5]longitude	[6]se	[7]R^2	[8]avp
2%									
	constant	area		precip					
ols	-3.7636	1.013		3.3227			0.27	0.91	0.084
wls	-4.1609	1.0504		3.5268			0.28	0.91	0.060
gls	-4.2348	1.0427		3.5289			0.30	0.89	0.056
	constant	area	elevation	precip					
ols	28.3375	1.0905	-8.0837	2.8677			0.20	0.95	0.047
wls	25.5164	1.102	-7.4758	3.1274			0.20	0.95	0.027
gls	20.9166	1.0971	-6.3088	3.1346			0.22	0.94	0.030
	constant	area	elevation		snow				
ols	40.882	0.9806	-11.3537		2.0875		0.18	0.96	0.038
wls	42.2588	0.8891	-11.9081		2.4461		0.19	0.96	0.015
gls	41.0838	0.9222	-11.5941		2.4171		0.19	0.96	0.021
4%									
	constant	area		precip					
ols	-3.9375	0.9955		3.3775			0.24	0.93	0.067
wls	-4.3291	1.0264		3.5847			0.25	0.93	0.048
gls	-4.3862	1.0233		3.5805			0.26	0.91	0.045
	constant	area	elevation	precip					
ols	23.0342	1.0606	-6.792	2.9952			0.19	0.96	0.042
wls	20.8327	1.0701	-6.336	3.2412			0.19	0.96	0.025
gls	16.8238	1.0678	-5.3176	3.2437			0.21	0.95	0.028
	constant	area	elevation		snow				
ols	36.2263	0.9534	-10.2084		2.1416		0.18	0.96	0.037
wls	38.0647	0.8688	-10.8547		2.4563		0.18	0.96	0.017
gls	37.1691	0.9	-10.6206		2.4426		0.18	0.96	0.022
10%									
	constant	area	precip						
ols	-4.2365	0.9731	3.4775				0.21	0.95	0.048
wls	-4.5952	0.9947	3.6739				0.21	0.95	0.035
gls	-4.6288	0.9966	3.6629				0.22	0.94	0.034
	constant	area	elevation	precip					
ols	15.4238	1.0205	-4.9508	3.1988			0.17	0.96	0.036
wls	13.9707	1.0272	-4.6693	3.4073			0.18	0.96	0.024
gls	10.9192	1.0272	-3.8941	3.4092			0.19	0.96	0.026
	constant	area	elevation		snow				
ols	29.6292	0.916	-8.6008		2.2365		0.18	0.96	0.038
wls	31.4896	0.8501	-9.2		2.4605		0.18	0.96	0.021
gls	31.0127	0.874	-9.0837		2.4671		0.18	0.96	0.026

[1]drainage area (square miles), [2]mean annual precipitation (inches), [3]mean annual maximum snow fall (inches), [4]elevation (feet msl) [5]longitude (absolute decimal degrees), [6]standard error ($\log_{10}$), [7]multiple coefficient of determination (adjusted) R^2 ($\log_{10}$), [8]average prediction error ($\log_{10}$)

Table 6.8: Lake Tahoe Regression parameters, error measures for 0.2, 0.5annual peak quantiles

	constant	[1]area	[2]map	[3]snow	[4]elevation	[5]longitude	[6]se	[7]R^2	[8]avp
20%									
	constant	area		precip					
ols	-4.5516	0.9581		3.5882			0.18	0.96	0.037
wls	-4.8603	0.972		3.7619			0.18	0.96	0.027
gls	-4.8776	0.9762		3.7488			0.19	0.96	0.027
	constant	area	elevation	precip					
ols	9.0038	0.9908	-3.4135	3.3961			0.17	0.97	0.033
wls	8.0052	0.9951	-3.2301	3.564			0.17	0.96	0.023
gls	5.7616	0.9957	-2.6617	3.5692			0.17	0.96	0.025
	constant	area	elevation		snow				
ols	24.1698	0.887	-7.2895		2.3378		0.18	0.96	0.040
wls	25.6065	0.8411	-7.7338		2.4797		0.18	0.96	0.027
gls	25.4465	0.8568	-7.7037		2.4968		0.19	0.96	0.031
50%									
	constant	area							
ols	0.7208	1.333					0.44	0.76	0.214
wls	0.7289	1.3278					0.44	0.76	0.206
gls	0.7276	1.3372					0.44	0.76	0.211
	constant	area	elevation						
ols	21.6458	1.3542	-5.3879				0.43	0.77	0.217
wls	21.8881	1.3476	-5.4476				0.43	0.77	0.208
gls	22.1133	1.3553	-5.5048				0.43	0.77	0.213
	constant	area		precip					
ols	-5.2525	0.9469		3.8472			0.15	0.97	0.027
wls	-5.4626	0.9488		3.9727			0.15	0.97	0.019
gls	-5.4765	0.9553		3.9699			0.16	0.97	0.021
	constant	area			snow				
ols	-4.946	0.828			2.5674		0.23	0.94	0.060
wls	-5.0068	0.8149			2.5987		0.23	0.94	0.053
gls	-5.078	0.8277			2.6246		0.23	0.94	0.057
	constant	area	elevation	precip					
ols	-1.3123	0.9564	-0.9922	3.7914			0.16	0.97	0.029
wls	-1.8356	0.9562	-0.9059	3.9051			0.16	0.97	0.022
gls	-2.986	0.9592	-0.6191	3.9184			0.16	0.97	0.023
	constant	area	elevation		snow				
ols	15.7255	0.8497	-5.3206		2.5638		0.19	0.95	0.045
wls	16.6475	0.8252	-5.5771		2.6069		0.19	0.95	0.035
gls	17.0044	0.8355	-5.6845		2.6339		0.20	0.95	0.039
	constant	area				long			
ols	-2182.95	1.2151				1050.252	0.24	0.93	0.064
wls	-2189.27	1.2168				1053.291	0.24	0.93	0.057
gls	-2167.37	1.2211				1042.757	0.24	0.93	0.062

[1]drainage area (square miles), [2]mean annual precipitation (inches), [3]mean annual maximum snow fall (inches), [4]elevation (feet msl) [5]longitude (absolute decimal degrees), [6]standard error ($\log_{10}$), [7]multiple coefficient of determination (adjusted) R^2 ($\log_{10}$), [8]average prediction error ($\log_{10}$)

Table 6.9: Lake Tahoe Regression parameters, error measures for 0.8, 0.9, annual peak quantiles

	constant	[1]area	[2]map	[3]snow	[4]elevation	[5]longitude	[6]se	[7]R^2	[8]avp
80%									
	constant	area		precip					
ols	-6.0877	0.9614		4.169			0.16	0.97	0.030
wls	-6.1442	0.9428		4.2198			0.16	0.97	0.019
gls	-6.2034	0.9493		4.2644			0.16	0.97	0.022
	constant	area	elevation	precip					
ols	-8.9278	0.9546	0.7152	4.2093			0.17	0.97	0.033
wls	-8.8764	0.9369	0.6845	4.2661			0.17	0.97	0.022
gls	-8.439	0.9451	0.5572	4.3094			0.17	0.97	0.024
	constant	area	elevation		snow				
ols	10.0222	0.839	-4.0907		2.8316		0.21	0.95	0.055
wls	11.5307	0.8044	-4.4546		2.8102		0.22	0.95	0.036
gls	13.8325	0.8293	-5.0653		2.8513		0.23	0.94	0.048
90%									
	constant	area		precip					
ols	-6.5833	0.9811		4.364			0.18	0.96	0.039
wls	-6.511	0.9439		4.3537			0.19	0.96	0.022
gls	-6.5624	0.9454		4.4023			0.19	0.96	0.023
	constant	area	elevation	precip					
ols	-11.7207	0.9687	1.2937	4.4369			0.19	0.96	0.042
wls	-11.5323	0.9318	1.255	4.4471			0.19	0.96	0.024
gls	-10.6302	0.9364	1.0134	4.4863			0.20	0.96	0.026
	constant	area	elevation		snow				
ols	8.2454	0.8461	-3.7719		2.9884		0.23	0.94	0.066
wls	10.238	0.7939	-4.2319		2.9308		0.24	0.94	0.034
gls	12.5015	0.8153	-4.8214		2.9554		0.25	0.93	0.047

[1]drainage area (square miles), [2]mean annual precipitation (inches), [3]mean annual maximum snow fall (inches), [4]elevation (feet msl) [5]longitude (absolute decimal degrees), [6]standard error ($\log_{10}$), [7]multiple coefficient of determination (adjusted) R^2 ($\log_{10}$), [8]average prediction error ($\log_{10}$)

Table 6.10: Lake Tahoe Regression parameters, error measures for 0.95, 0.99, annual peak quantiles

	constant	[1]area	[2]map	[3]snow	[4]elevation	[5]longitude	[6]se	[7]R^2	[8]avp
95%									
	constant	area							
ols	0.0261	1.4574					0.53	0.73	0.311
wls	0.1006	1.3976					0.53	0.72	0.270
gls	0.1166	1.4104					0.54	0.72	0.281
	constant	area	elevation						
ols	14.5174	1.4721	-3.7313				0.54	0.72	0.335
wls	15.5909	1.4145	-3.9891				0.54	0.72	0.291
gls	16.4068	1.4256	-4.1946				0.54	0.71	0.300
	constant	area		precip					
ols	-7.0157	1.0023		4.5354			0.21	0.96	0.053
wls	-6.8146	0.9455		4.4652			0.22	0.95	0.025
gls	-6.858	0.9428		4.5149			0.23	0.95	0.026
	constant	area			snow				
ols	-6.8767	0.8423			3.1274		0.27	0.93	0.082
wls	-6.6072	0.7672			3.0565		0.28	0.93	0.039
gls	-6.612	0.7886			3.0718		0.29	0.92	0.054
	constant	area	elevation	precip					
ols	-13.5031	0.9866	1.6337	4.6274			0.22	0.95	0.057
wls	-13.4294	0.9283	1.6519	4.5925			0.23	0.95	0.028
gls	-12.3739	0.9294	1.3742	4.6294			0.24	0.95	0.029
	constant	area	elevation		snow				
ols	7.3012	0.8572	-3.6492		3.125		0.26	0.93	0.081
wls	9.5139	0.7844	-4.1397		3.0372		0.27	0.93	0.032
gls	11.7671	0.8023	-4.7187		3.0506		0.28	0.92	0.044
	constant	area				long			
ols	-2515.64	1.3216				1209.926	0.32	0.90	0.115
wls	-2412.24	1.2819				1160.225	0.32	0.90	0.086
gls	-2411.93	1.2826				1160.082	0.32	0.90	0.089
99%									
	constant	area		precip					
ols	-7.9481	1.0633		4.914			0.30	0.92	0.107
wls	-7.4197	0.9546		4.6926			0.33	0.91	0.037
gls	-7.4826	0.9402		4.7821			0.35	0.90	0.035
	constant	area	elevation	precip					
ols	-15.5464	1.045	1.9134	5.0217			0.31	0.92	0.116
wls	-15.8938	0.9309	2.1163	4.8574			0.33	0.91	0.041
gls	-14.1402	0.9219	1.6562	4.9289			0.36	0.89	0.040
	constant	area	elevation		snow				
ols	6.9928	0.9012	-3.8193		3.4078		0.34	0.90	0.141
wls	8.7706	0.7711	-4.1392		3.2597		0.37	0.89	0.033
gls	13.121	0.7958	-5.234		3.2507		0.40	0.87	0.051

[1]drainage area (square miles), [2]mean annual precipitation (inches), [3]mean annual maximum snow fall (inches), [4]elevation (feet msl) [5]longitude (absolute decimal degrees), [6]standard error ($\log_{10}$), [7]multiple coefficient of determination (adjusted) R^2 ($\log_{10}$), [8]average prediction error ($\log_{10}$)

Table 6.11: Summary best regional regression for peak annual quantiles
(Regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50)

[8]probability	constant (b_0)	[1]area (b_1)	[2]elevation (b_2)	[4]snow (b_3)	[5]se	[6]R^2	[7]avp
Best regression							
0.002	51.4905	1.0048	-14.1498	2.282	0.22	0.95	0.16
0.01	44.5481	0.9463	-12.4502	2.3831	0.19	0.96	0.15
0.02	41.0838	0.9222	-11.5941	2.4171	0.19	0.96	0.14
0.04	37.1691	0.9	-10.6206	2.4426	0.18	0.96	0.15
0.1	31.0127	0.874	-9.0837	2.4671	0.18	0.96	0.16
	constant (b_0)	[1]area (b_1)	[2]elevation (b_2)	[3]map (b_3)	[5]se	[6]R^2	[7]avp
Recommended regression							
[9]0.002	33.5078	1.1884	-9.3726	2.8118	0.29	0.91	0.20
0.01	23.3825	1.1254	-6.8861	3.0215	0.25	0.93	0.18
0.02	20.9166	1.0971	-6.3088	3.1346	0.22	0.94	0.17
0.04	16.8238	1.0678	-5.3176	3.2437	0.21	0.95	0.17
0.1	10.9192	1.0272	-3.8941	3.4092	0.19	0.96	0.16
0.2	5.7616	0.9957	-2.6617	3.5692	0.17	0.96	0.16
0.50	-5.4765	0.9553	3.9699		0.16	0.97	0.14
0.80	-6.2034	0.9493	4.2644		0.16	0.97	0.15
0.90	-6.5624	0.9454	4.4023		0.19	0.96	0.15
0.95	-6.8580	0.9428	4.5149		0.23	0.95	0.16
0.99	-7.4826	0.9402	4.7821		0.35	0.90	0.19

[1]drainage area (square miles), [2]mean annual precipitation (inches), [3]elevation (feet msl), [4]mean annual snowfall (inches), [5]standard error ($\log_{10}$), [6]multiple coefficient of determination (adjusted) R^2 ($\log_{10}$), [7]average prediction error ($\log_{10}$)

[8]best regression: (application limited to drainage areas > 0.5 sq miles, basin average elevation > 7000 (ft msl) see discussion.

$\log_{10}(Q_p)=b_0 + b_1\log_{10}(\text{area}) + b_2\log_{10}(\text{elevation}) + b_3\log_{10}(\text{snow})$ p=0.1 to 0.002

[9]recommended regression: application limited to drainage areas > 0.5 sq miles, basin average elevation > 7000 (ft msl) see discussion.

$\log_{10}(Q_p)=b_0 + b_1\log_{10}(\text{area}) + b_2\log_{10}(\text{elevation}) + b_3\log_{10}(\text{map})$ p=0.2 to 0.002

$\log_{10}(Q_p)=b_0 + b_1\log_{10}(\text{area}) + b_2\log_{10}(\text{map})$ p=0.5 to 0.99

(recommended regressions result in predictions **10% less** then best regression predictions over all gages used in study)

Table 6.12 Regression sensitivity to large area Upper Truckee River and Trout Creek gages

scenario	constant (b_0)	[1]area (b_1)	[2]elevation (b_2)	[4]snow (b_3)	[10]difference
[9]18 gages 0.01 probability	45.1928	-12.3965	1.142	1.9822	
all gages	44.5481	-12.4502	0.9463	2.3831	
	average difference over 18 gages				15%
	constant (b_0)	[1]area (b_1)	[2]elevation (b_2)	[3]map (b_3)	
18 gages 0.5 probability	-5.1493	1.0063	3.7595		
all gages	-5.4765	0.9553	3.9699		
	average difference over 18 gages				5%

[1]drainage area (square miles), [2]mean annual precipitation (inches), [3]elevation (feet msl), [4]mean annual snowfall (inches), [5]standard error ($\log_{10}$), [6]multiple coefficient of determination (adjusted) R^2 ($\log_{10}$), [7]average prediction error ($\log_{10}$)

[8]general regressions:

$\log_{10}(Q_p)=b_0 + b_1\log_{10}(\text{area}) + b_2\log_{10}(\text{elevation}) + b_3\log_{10}(\text{snow})$ p=0.01

$\log_{10}(Q_p)=b_0 + b_1\log_{10}(\text{area}) + b_2\log_{10}(\text{elevation}) + b_3\log_{10}(\text{map})$ p=0.2

[9]Large area gages omitted from data, Upper Truckee River (USGS ID 10336610 and Trout Creek (USGS ID 10336780)

[10]average regression predictions difference over all gages, **[**(18 gage regression) – all gage regression)**]**/(all gage regression)

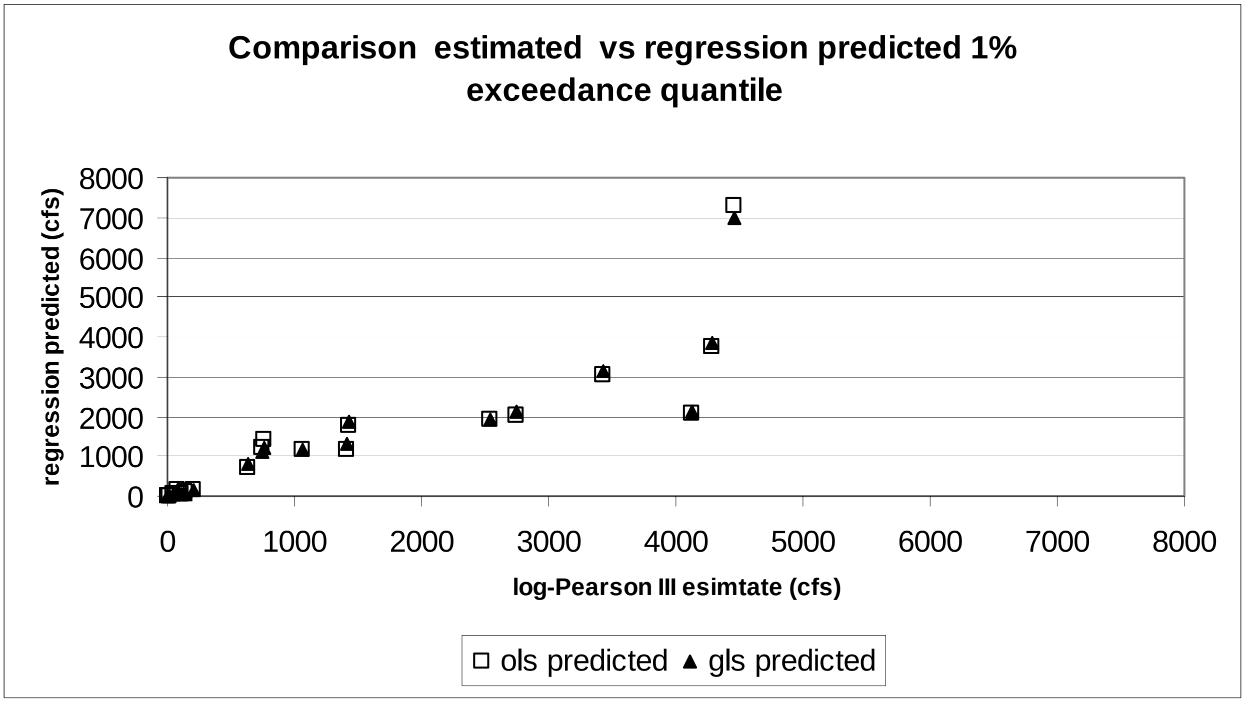

Figure 6.2: Lake Tahoe gages, log- Pearson III estimates vs. regression prediction (area, elevation and basin average snowfall depth) comparison

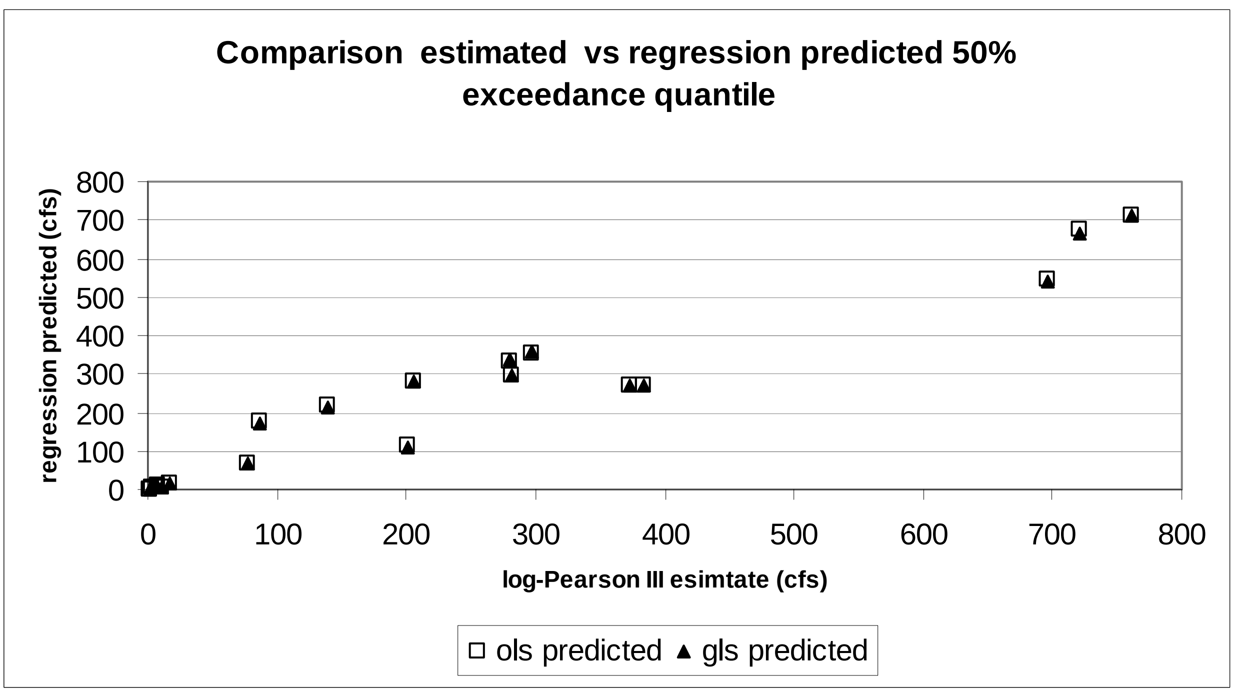

Figure 6.3: Lake Tahoe gages, log- Pearson III estimates vs. regression prediction (area and basin average mean annual precipitation) comparison,50% peak annual events

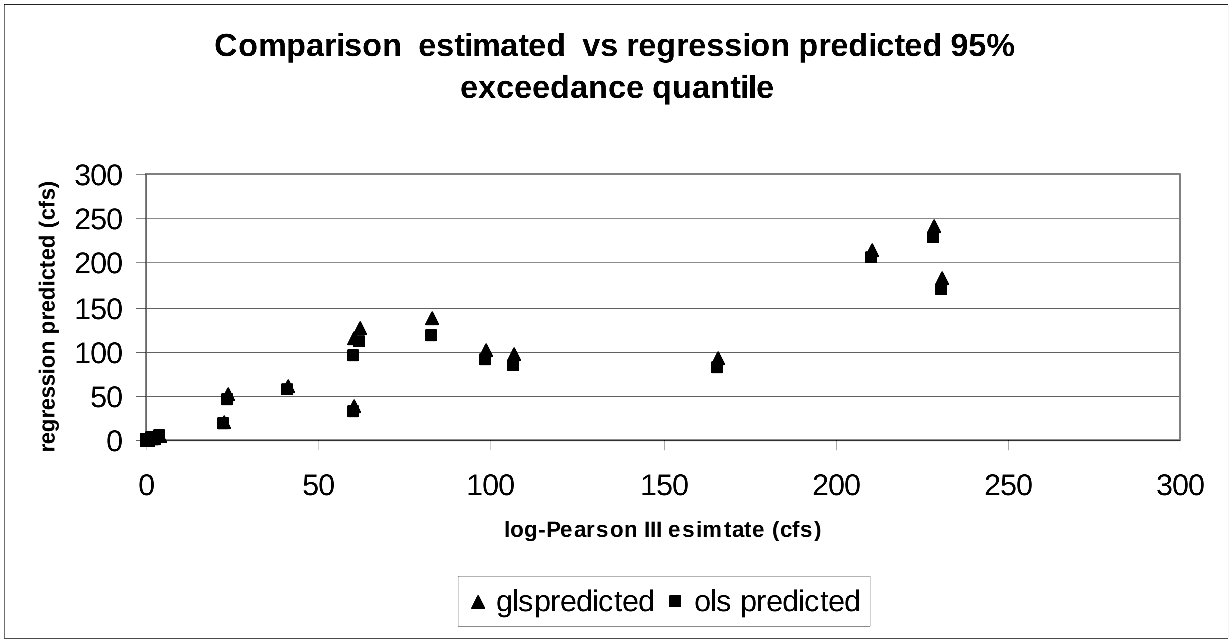

Figure 6.4: Lake Tahoe gages, log- Pearson III estimates versus regression prediction (area and basin average mean annual precipitation) comparison, 95% peak annual events

6.4. Comparison of regression equations

The purpose of this section is to compare the peak annual flow regression predictions of the 1% peak annual flow (Table 6.11)with those obtained from the regional gages (see Table 2.1), those available from the USGS (see, Blakemoore, et al., 1997) and from a study done by HYDMET (see Shively and Clyde, 2004). The USGS regressions used gages obtained from a much larger area than the Tahoe Basin used in this study, covering the southern range of the Sierra Nevada. Table 6.13 shows the gages used in the HYDMET study. The GLS regression using regional gages covers an area and number of gages similar to that of the USGS study. Table 6.14 summarizes the source and relatively accuracy of the regression equations used in the comparison.

The difference between the study estimates and these other regression estimates for the 1% exceedance peak annual flow are shown in Table 6.15. The fraction difference for the comparison with the USGS equations is very large, and is possibly due to: 1) the very different size of the study areas; 2) the difference in drainage areas studied (the USGS study average drainage areas size being much larger than for Lake Tahoe); 3) the different gages used (the USGS study had only a few Lake Tahoe gages); and 4) the difference in period of record (regressions for the Lake Tahoe Basin used historic weighting of the 1997 event and consider an additional period of record up to water year 2001).

The differences found in comparisons with the USGS study are surprising given the much smaller differences found in comparison with the predictions obtained from the regressions using the regional gages (see Table 2.1). Since the regional regression uses gages from about the same area as the USGS, one might expect similar results. The differences between the USGS gages and the regressions obtained for the regional gages may be due to differences in record length and differences in total number of gages. In any case, the difference between the regression relationship for the Lake Tahoe Basin gages and the regional gages is still relatively large, being on the order of 70% and biased (the regressions of Table 6.1 predicting smaller 1% discharges).

This study and HYDMET regression equations agree much more closely. Although the predictions agree on the average, a directional bias exist from east to west where the Lake Tahoe Basin regressions are greater for western study gages and less than the HYDMET estimates for eastern gages. The difference is partly due to the preponderance of eastern gages in the HYDMET study (note the gages with longitudes less than 120.0 degrees in Table 6.13); and, partly due to the lower estimates of the 1% flow obtained from frequency analysis for Lake Tahoe eastern gages than would be expected from the HYDMET regression predictions.

Typical of the large difference for eastern gages is the comparison with the Eagle Rock gage (see Table 6.15). Notice that the prediction fraction difference is about double, although the absolute difference (less than 15 cfs) is not large. Still from a drainage design point of view this difference may be significant. Note also that the regression estimate from the regional regressions is closer to the HYDMET values, but that the USGS regressions predict much greater values.

The Eagle Rock gage, as well as a number of the other smaller area Lake Tahoe Basin gages had short systematic record lengths of 11 years. The Eagle Rock gage frequency curve estimated for use in the study regression analysis used a historic weighting of the 1997 event. The Lake Tahoe Basin regression estimate of the 1% discharge for this gage of 5.8 cfs (see Table 6.16) is in reasonable agreement with the estimate obtained from the gage statistics of 3.7 cfs (see Table 6.16). However, the HYDMET estimate at this gage was 18.9 cfs. Consequently, a possible cause of the difference between the HYDMET and this study regression predictions could be an unreasonably small estimate of the smaller area gage frequency curve quantiles , and the estimate for the Eagle Rock gage curve in particular, caused by the short systematic record and the assumed historic period.

The reasonableness of the basic flow frequency analysis for the Eagle Rock Creek gage was examined to see if the study regression estimates were significantly low as indicated by the HYDMET regression estimate. This was done by examining the gage statistics derived for the gage. Figure 6.5 shows the mean of the log-annual peaks for this gage in comparison to other Lake Tahoe gages as part of the scatter resulting from an OLS regression analysis using drainage area and map (mean annual precipitation) as independent variables. As can be seen, the estimated mean for Eagle Rock Creek is very consistent with those for the other gages (note regression R^2=0.97).

Figures 6.6 and 6.7 show the variation of the standard deviation of the log-flows as a function of both drainage area and elevation. Apparently, the variation of standard deviation is very consistent with elevation but not drainage area. An OLS regression analysis demonstrated that of the independent variables tested in the previous section, elevation and map best explained the variation of standard deviation among Lake Tahoe gages (R^2=0.55, the coefficients of the regression were found statistically significant at the 5% level). Figure 6.8 shows the regression prediction and gage estimated standard deviations. The plot indicates that the gage estimate of the standard deviation for Eagle Rock Creek does not appear from inspection to be an outlying value at least in terms of the general regression scatter.

Finally, the reasonableness of the gage frequency analysis estimate of the 1% discharge was examined by performing a sensitivity analysis on gage statistics as shown in Table 6.15. The statistics were varied to increase the 1% discharge estimate by increasing the standard deviation and skew to the average value for all gages used in the study area, and, by using the mean from the systematic period alone. The maximum 1% flow estimate was computed to be 9.4 cfs, which is still only about half of the HYDMET regression estimate.

In conclusion, if the gage records are a good indication, then the HYDMET and regional gage regressions probably overestimates the 1% exceedance discharges for the smaller eastern drainage area gages in the study area. The USGS predictions would seem to be unreasonably large. The smaller predictions for the more western study area gages is perhaps to be expected given that the HYDMET study did not include many gages from this region.

In summary, the regression comparisons at the 1% exceedance peak annual discharges demonstrated large difference between the USGS and this study's estimates but agreement on the average in comparison of the HYDMET and this study's regression estimates. The differences in predictions with this study's regional gage regression estimates was significantly smaller than the USGS equations, but, still significant. The difference with the USGS regression predictions can be explained by the very different sources of data employed in both studies. The same probably can be said for the differences found in comparison with the regional gage regression equations. Although agreement was obtained on the average, there was a significant east-west location bias in the regression prediction differences with the HYDMET data. A sensitivity analysis of the Eagle Rock Creek gage peak annual frequency curve showed that the HYDMET regressions over predicted the 1% discharge for the eastern gages. The HYDMET smaller predictions in comparison with this studies regression prediction for the western gages is probably due to the lack of western gages used in the HYDMET analysis.

Table 6.13: Gage data HYDMET study (see Shively and Clyde, 2004)

USGS No.	Description	Latitude	Longitude	Area (sq-mi)	Begin Record	End Record	100-Yr	Remarks
10304500	Silver Cr below Penn Cr nr Markleeville	38.5999	-119.7760	19.60	1947	1973	3600	Fair
10308100	Millberry Cr at Markleeville	38.6999	-119.7843	5.10	1963	1973	500	very poor
10310000	W F Carson River at Woodfords	38.7696	-119.8338	65.40	1890	2001	8500	Good
10336688	First Ck nr Crystal Bay	39.2500	-119.9883	1.07	1970	2000	30	Fair
10336691	Second Ck at Lakeshore Drive nr Cry B	39.2494	-119.9764	1.33	1991	2000	30	Maximum
10336694	Wood Ck at Mouth nr Crystal Bay	39.2431	-119.9583	1.97	1970	2000	60	Maximum
10336696	Third Ck at Village Blvd, Incline Village	39.2631	-119.9442	4.00	1991	2000	80	Maximum
10336700	Incline Cr nr Crystal Bay	39.2403	-119.9439	6.69	1969	2002	200	Fair
10336715	Marlette C nr Carson City	39.1722	-119.9069	2.86	1974	2001	100	lake reg
10337900	Truckee R Tributary nr Truckee	39.2799	-120.2069	1.11	1963	1973	400	Fair
10339200	Middle Martis Cr nr Truckee	39.2819	-120.1044	2.83	1964	1973	100	very poor
10340500	Prosser Cr nr Truckee	39.3732	-120.1316	52.90	1943	2003	5000	Poor
10343500	Sagehen Cr nr Truckee	39.4316	-120.2380	10.50	1954	2003	1400	Good
10344400	Little Truckee R nr Truckee	39.4357	-120.0844	146.00	1904	2003	14000	Good
10347310	Dog Creek at Verdi	39.5244	-119.9944	24.20	1994	1998	3500	very poor
10347600	Hunter C nr Reno	39.4903	-119.8986	11.50	1962	1981	1400	Fair
10347800	Peavine C nr Reno	39.5431	-119.8653	2.34	1963	1974	350	very poor
10348460	Franktown C nr Carson City	39.2033	-119.8714	3.24	1975	2001	400	Good
10348850	Galena C at Galena C State Park	39.3544	-119.8575	7.69	1984	2001	1500	Fair
10349300	Steamboat C at Steamboat	39.3778	-119.7425	123.00	1962	2000	6500	Fair
10351850	Pyramid Lk Tr nr Nixon	39.8583	-119.4756	1.94	1968	2000	500	Fair

Table 6.14 Regression equations source, error measures

Source	[1]avp	[2]%error
Table 6.11	0.18	51%
HYDMET (see Shively and Clyde, 2004)	-----	----
Regional gages (see Table 2.1)	0.27	89%
(Blakemoore, et al., 1997)	0.29	95%

[1]average prediction error (log cfs)

[2]100(gage estimate- regression prediction)/regression prediction = $10^{avp} - 1$

Table 6.15. Comparison of Prediction Equation 1% Flood

Location	USGS ID	area (sq-mi)	elevation (ft)	latitude (degrees)	[1]MAP (inches)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
UPPER TRUCKEE	10336580	14.09	8258.59	38.79630	51.9	768	423	-0.45	1485	0.93	790	0.03
UPPER TRUCKEE	10336600	33.1	8042.35	38.84296	50.4	2208	993	-0.55	3632	0.65	1666	-0.25
UPPER TRUCKEE	103366092	34.28	7996.26	38.84852	51.8	2595	1028	-0.60	4135	0.59	1737	-0.33
UPPER TRUCKEE	10336610	54.9	7614.23	38.92241	47.0	4605	1647	-0.64	6300	0.37	2883	-0.37
TAYLOR	10336626	16.7	7598.62	38.92157	50.9	1557	501	-0.68	2342	0.50	1141	-0.27
LAKE TAHOE TRIB	10336635	0.64	7106.5	39.01741	44.6	42	19	-0.54	80	0.90	107	1.55
GENERAL	10336645	7.44	7196.71	39.05185	48.4	783	223	-0.71	1126	0.44	721	-0.08
BLACKWOOD	10336660	11.2	7262.68	39.10741	54.8	1695	336	-0.80	2262	0.33	996	-0.41
WARD	10336674	4.96	7531.76	39.14074	67.6	995	149	-0.85	1468	0.48	493	-0.50
WARD	10336675	8.97	7341.47	39.13685	62.1	1788	269	-0.85	2382	0.33	828	-0.54
WARD	10336676	9.7	7288.91	39.13213	60.1	1859	291	-0.84	2437	0.31	892	-0.52
WOOD	10336693	1.69	8198.86	39.26130	41.6	38	51	0.33	101	1.66	186	3.88
GLENBROOK	10336730	4.11	7349.24	39.08741	26.6	57	123	1.16	121	1.13	440	6.71
LOGAN HOUSE	10336740	2.09	7816.76	39.06657	29.7	24	63	1.61	64	1.65	224	8.35
EDGEWOOD	10336756	0.81	7615.31	38.97546	28.3	9	24	1.70	24	1.66	109	11.11
EDGEWOOD	103367585	3.13	7529.35	38.96657	29.0	46	94	1.04	105	1.28	320	5.96
EAGLE ROCK	103367592	0.63	8286.26	38.95657	31.1	5	19	2.78	17	2.38	74	13.78
TROUT	10336770	7.4	8606.66	38.86324	42.4	152	222	0.46	392	1.58	449	1.95
TROUT	10336775	23.7	7820.54	38.90339	40.7	963	711	-0.26	1676	0.74	1399	0.45
TROUT	10336780	36.7	7931.58	38.91991	38.8	1238	1101	-0.11	2172	0.75	1923	0.55
					average			0.06		0.93		2.55
					max			2.78		2.38		13.78
					min			0.11		0.31		0.03

[1]Mean annual precipitation

(1) $\log_{10}(Q_{1\%}) = 23.3825 + 1.1254\log_{10}(\text{area}) - 6.886\log_{10}(\text{elevation}) + 3.0215\log_{10}(\text{MAP})$ (see Table 5.1)

(2) $Q_{1\%} = 30.0\ (\text{area})$ (see Shively and Clyde, 2004)

(3) fraction difference = [(2)-(1)]/(1)

(4) $\log_{10}(Q_{1\%}) = 13.1691 + 1.0121\log_{10}(\text{area}) - 3.9758\log_{10}(\text{elevation}) + 2.5728\log_{10}(\text{MAP})$ (see Table 2.1, SPK 2005 a)

(5) fraction difference = [(4)-(1)]/(1)

(6) $\log10(Q_{1\%}) = \log_{10}(7000) + 0.782\log_{10}(\text{area}) - 2.18\log_{10}(\text{elevation}/1000) +$
$4.6\log_{10}([\text{latitude}-28]/10)$ (Blakemoore, et al., 1997)

(7) fraction difference = [(6)-(1)]/(1)

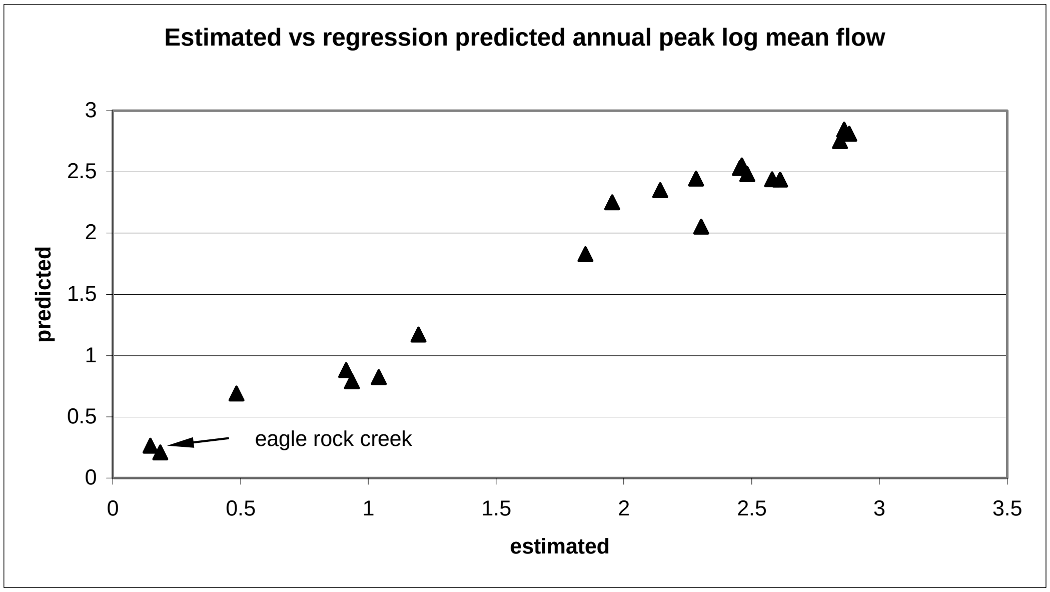

Figure 6.5 : Regression predicted versus observed annual peak log mean flow
R^2=0.97,$\log_{10}$(mean) = -5.3533 + 0.970351[log10(area)] + 3.894182[$\log_{10}$(map)], area in square miles, map = mean annual precipitation (inches)

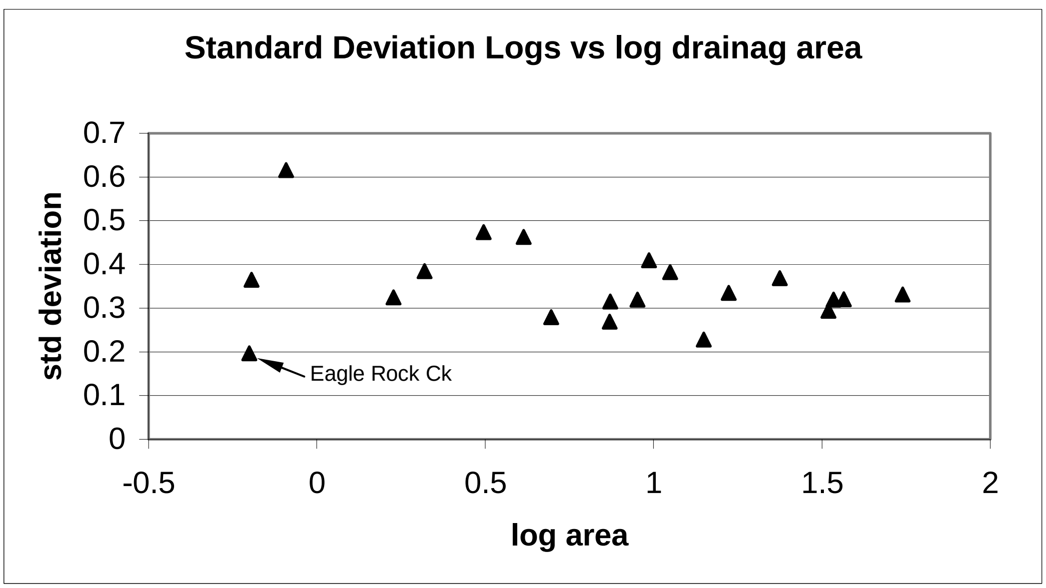

Figure 6.6: Standard deviation of log flows versus log drainage area

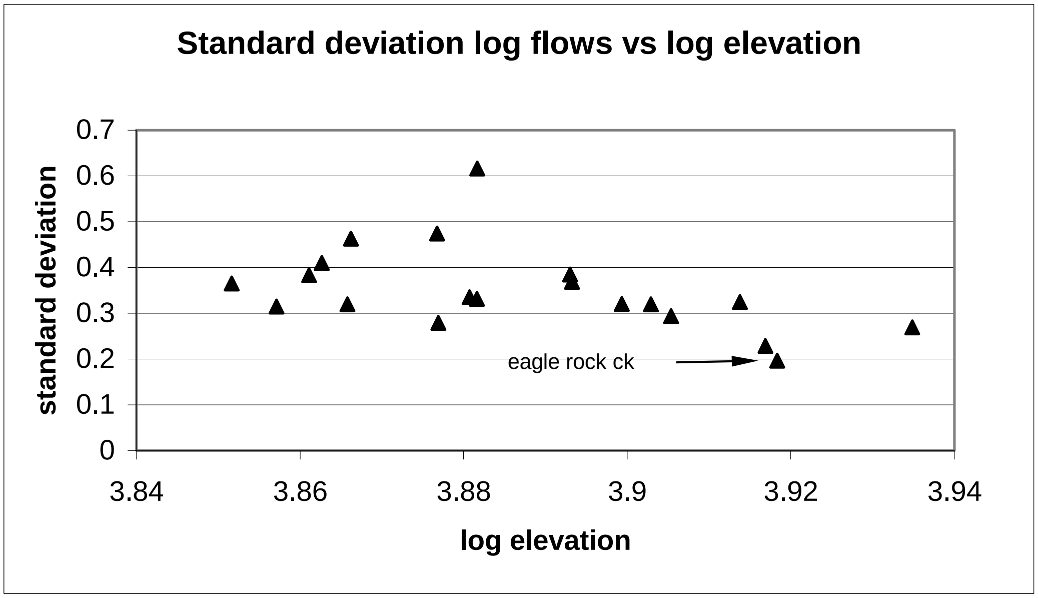

Figure 6.7: Standard deviation of log flows versus log elevation

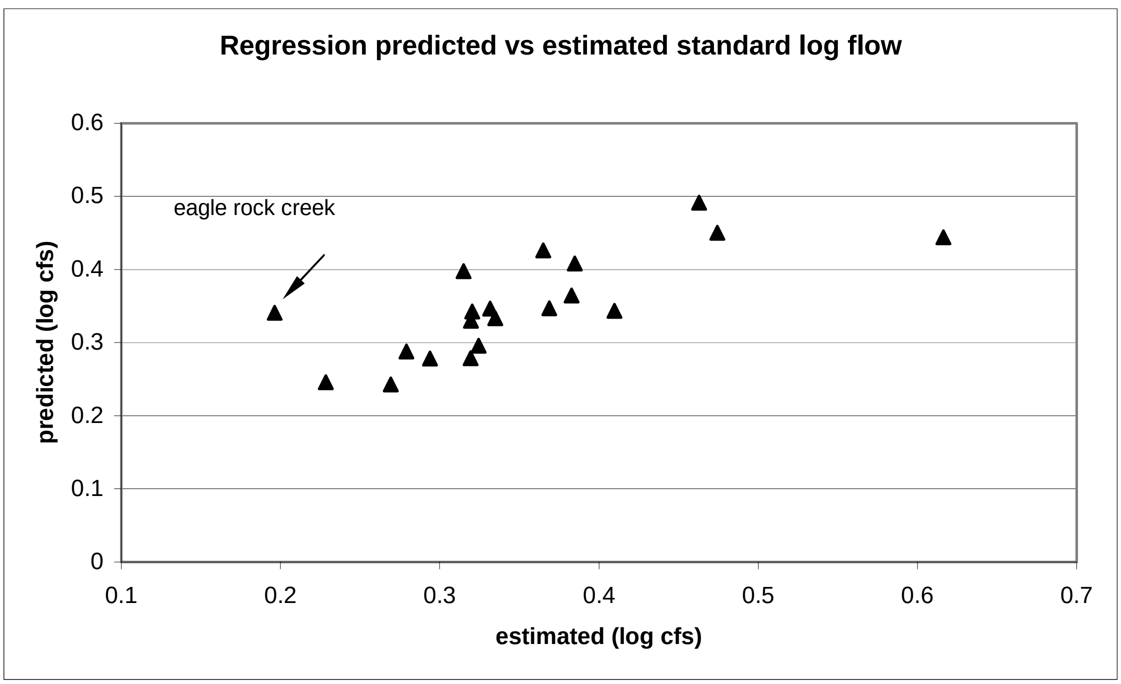

Figure 6.8: Regression predicted versus estimated log standard deviation annual peak flows
R^2 = 0.55, $\log_{10}$(std dev) = 10.07757 - 2.316831[log10(elevation] + -2.31683 [$\log_{10}$(map)]

Table 6.16: Eagle Rock Creek sensitivity analysis 1% peak annual flow

scenario	[1]mean	[2]std dev	[3]skew	1%
[4]**historic period of record (102 years) gage statistics**	**0.148**	**0.1964**	**-0.49**	**3.7**
historic period of record mean and standard deviation, average skew for all gages	0.148	0.1964	-0.10	4.0
historic period of record mean, average skew and standard deviation for all gages	0.148	0.3500	-0.10	8.6
gage estimates, systematic record	0.186	0.2358	-0.14	5.1
systematic period (11years) mean, historic period average skew and standard deviation for all gages	0.186	0.3500	-0.10	9.4

[1]mean (log flows), [2]standard deviation (log flows), [3]skew coefficient (log flows)
[4]gage statistics used in developing study regression for Lake Tahoe basin

7. Split sample testing

7.1. Introduction

The purpose of this section is to describe the flow record split sample testing used to assess the predictive capability of the regression approach to estimating peak flow regression equations described in section 6. The tests were performed by estimating regression equations for frequency curve estimates obtained for half the record of selected regional gages, and then obtaining the regression prediction error based on comparison with the frequency curve estimates obtained from the remaining (or reserved) portion of the data. A comparison of the regression standard error and the prediction error provides a measure of the regression predictive capability.

A split sample testing approach was chosen because general tests for evaluating the statistical significance of regression equations estimated using generalized least squares (GLS) do not exist. This is primarily due to the nature of regression residuals which do not meet the distributional requirements needed to apply statistical significance tests developed for ordinary least squares. Measuring the predictive capability of the regression equations provides an alternative measure of the regression equation significance.

Section 7.2 describes the criteria used for selecting gages, and the estimation of the log-Pearson III frequency curves. The assessment of regression predictive capability is given in section 7.3.

7.2. Annual peak frequency analysis

Gage were selected for split sample testing if: 1) the period of record was at least 18-years; and, 2) the gages formed consistent region as measured by the regression leverage statistic (see section 11, the technical appendix for a discussion of leverage). The limiting period of record was chosen so that split record would have at least 9 years of record. This is one year less than the “rule of thumb” recommendation given in the Bulletin 17B guidelines (IACWD, 1982). However, maximizing the number of gages is critical to a regional analysis; and consequently, this record length criteria was relaxed to include more gages in the analysis.

The records were split for the test by an alternating procedure where the 1,3,5, etc. years observations were place in one group and the remaining data was placed in a second group. This method for splitting the data removes any short term cycles or trends that can occur in peak flow series (see Bulletin 17B, IACWD, appendix 14, regional tests of distributions). Table 7.1 gives the $\log_{10}$ statistics of the peak annual flow obtained from both sets of data. The statistics of the first sample of the data reflect the historic weighting given the 1997 event, as was discussed in section 6. The second sample of data did not have the 1997 event, nor were any high-outliers found in the analysis.

Figures 7.1-7.3 provide some example comparison of log-Pearson III distributions estimated from both sets of data. Differences between the estimated 1%, 50% and 95% annual peak $\log_{10}$ quantiles estimated from both sets of data are shown in Figures 7.4-7.6. As can be seen from these figures, the two estimates generally agree, although there are a few gages where the differences in quantile estimates are significant.

7.3. Analysis of prediction error

Regression equation prediction error was assessed by comparing: 1) regression equations obtained from both sets of data; and, 2) comparing standard error estimated for regression equations obtained from the first set of data to prediction error for the second set of data. The comparison of regression equations is intended to measure both the consistency and average prediction capability of the regression method. Basically, this is a comparison of mean prediction. The advantage of this test is that is relatively unaffected by the sampling error in quantile estimates (e.g., the 1% chance flow) due to record length. The comparison of standard and prediction error is more difficult, because it relates to the error in an individual prediction. These errors are highly affected by record length, making the comparison of standard error estimates derived using historic weighting of the 1997 event difficult to compare to prediction error where quantiles estimates were obtained from data sets not including the 1997 event.

Table 7.2 shows the "best" regression equation coefficients obtained from the divided set of data using generalized least squares. As can be seen from Table 7.3, the average prediction difference over all the gages between the regressions was insignificant at the 1% and 50% exceedance frequency, and reasonably small at 13% for the 95% exceedance frequency. Consequently, the regression equation method produces reasonably consistent and accurate predictions on the average over all gages.

The prediction error for the regression equations obtained from the first set of data (see Table 7.2) was obtained by computing a prediction standard error. This prediction standard error is computed by first obtaining the difference between the regression prediction of a quantile (e.g. the 1% exceedance flood) with the at-gage estimate obtained from the second set of data. Each individual prediction error squared is then weighted by the ratio of the period of record at each gage to the total period of record for all the gages. The prediction standard error is the square root of the average of the sum of these weighted squared differences. The weighting of the at-site prediction errors is performed because the accuracy of estimated quantile, and the resulting error, from the second set of data is inversely proportional to the gage record length shown in Table 7.4.

The regression estimation error was computed alternatively as: 1) the standard error of the regression; 2) a record weighted standard error; and 3) the average prediction error (see section 11, the technical appendix). The record weighted standard error was obtained by weighting the error at each gage by the ratio of the systematic record shown in Table 7.4 to the effective historic record used in the GLS method to obtain the regression equation from the first set of the data (see section 11, the technical appendix for the computation of the effective historic record). This weighting was performed because the quantiles obtained from the second set of data were based on the systematic period; whereas, the regression equations were based on the effective historic record length show in the table. The effective record length correction was most important for the 1% event.

The various measures of regression error (standard error or average prediction error) are significantly less than the estimated prediction error as shown in Table 7.5. This indicate that the regression standard error probably gives an optimistic view of the accuracy of individual predictions. This result needs to be tempered by the difficulty in accounting for the effect of record length on an individual prediction accuracy. As can be seen from figures 7.4 – 7.6, a couple of gages in the comparisons generally deviate from the overall relationship between quantiles estimate from either set of the split data. These points tend to inflate the estimate of prediction error. Basically, the effects of differences in record are difficult to account for in comparing errors.

In summary, the regression method applied in the study seems to produce consistent and accurate estimates of peak flow quantiles on the average. However, individual regression prediction error estimates as measured by either the standard or average prediction error seem to be optimistic.

Table 7.1: Regional gages used in split sample testing, minimum 20 year total gage record, regionally consistent based on statistical leverage test.

gages id	gage location	[2]area	[2]mean	sd	skew	[3]mean	sd	skew
10265200	Convict Creek near Mammoth Lakes, CA	18.2	1.998	0.1849	-0.07	2.043	0.2158	-0.08
10265700	Rock Creek	35.8	2.034	0.2173	0.03	2.077	0.1988	-0.05
10267000	Pine Creek	36.4	2.371	0.172	-0.36	2.322	0.1896	-0.9
10276000	Big Pine Creek near Big Pine, CA	39.0	2.243	0.182	0.09	2.282	0.1653	-0.27
10291500	Buckeye Creek near Bridgeport, CA	44.1	2.657	0.2146	-0.09	2.531	0.1526	0.3
10292000	Swauger Creek near Bridgeport, CA	52.8	2.017	0.4109	0.14	1.871	0.4852	0.57
10299100	Desert Creek near Wellington, NV	50.4	1.691	0.3214	0.12	1.908	0.3358	0.28
10302010	Reese River Canyon near Schurz, NV	14.0	1.209	0.7443	-0.81	1.789	0.7712	0.38
10304500	Silver Creek below Pen Creek near Markleeville, CA	19.6	2.583	0.2293	1.37	2.718	0.305	0.92
10310000	West Fork Carson River at Woodfords, CA	65.4	2.932	0.2919	0.87	2.897	0.3096	0.2
10310500	Clear Creek near Carson City, NV	15.5	1.469	0.3922	0.24	1.424	0.4277	-0.13
10311450	Carson River near Carson City, NV	12.7	1.065	1.088	-1.76	0.317	1.2714	-0.3
10336600	Upper Truckee River at South Lake Tahoe, CA	33.1	2.839	0.2399	0.09	2.85	0.3499	-0.01
10336610	Taylor Creek near Camp Richardson, CA	54.9	2.838	0.2113	0.92	2.874	0.4124	-0.22
10336626	Blackwood Creek near Tahoe City, CA	16.7	2.591	0.4033	0.31	2.404	0.1559	-0.65
10336730	Glenbrook Creek at Glenbrook, NV	4.11	0.986	0.3979	0.22	0.878	0.5238	0.11
10343500	Sagehen Creek near Truckee, CA	10.5	2.02	0.4616	0.01	1.986	0.4603	-0.11

[1]Drainage area square miles
[2]Sample mean, standard deviation (sd), skew of log annual peak flows for half of record used to estimate regressions
[3]Sample mean, standard deviation (sd), skew of log annual peak flows for reserved data (remaining half) used to estimate regression prediction error

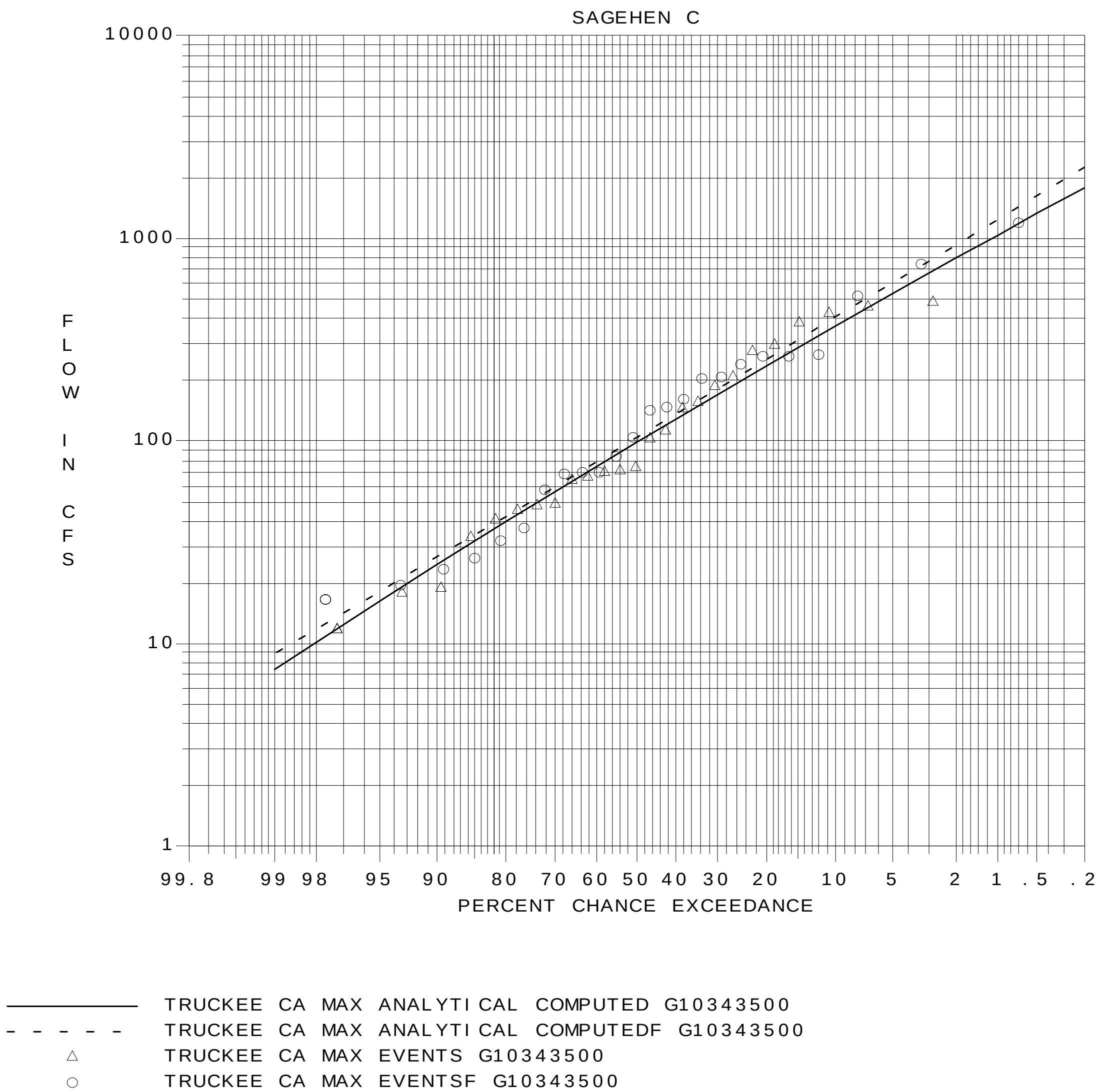

Figure 7.1: Split sample annual peak frequency analysis, Sagehen Creek near Truckee, USGS gage 10343600

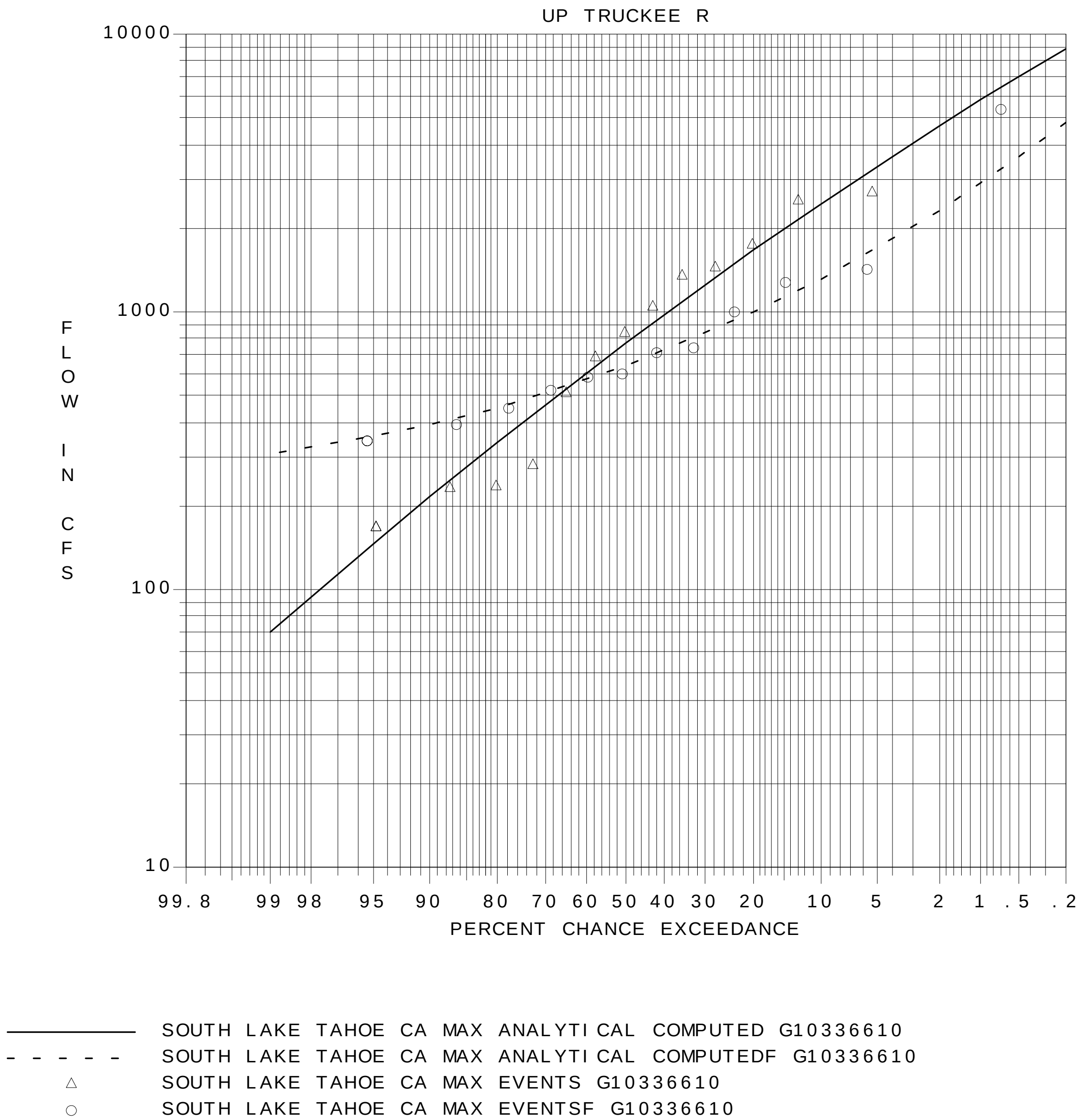

Figure 7.2: Split sample annual peak frequency analysis, Upper Truckee River at South Lake Tahoe, USGS gage 10336610

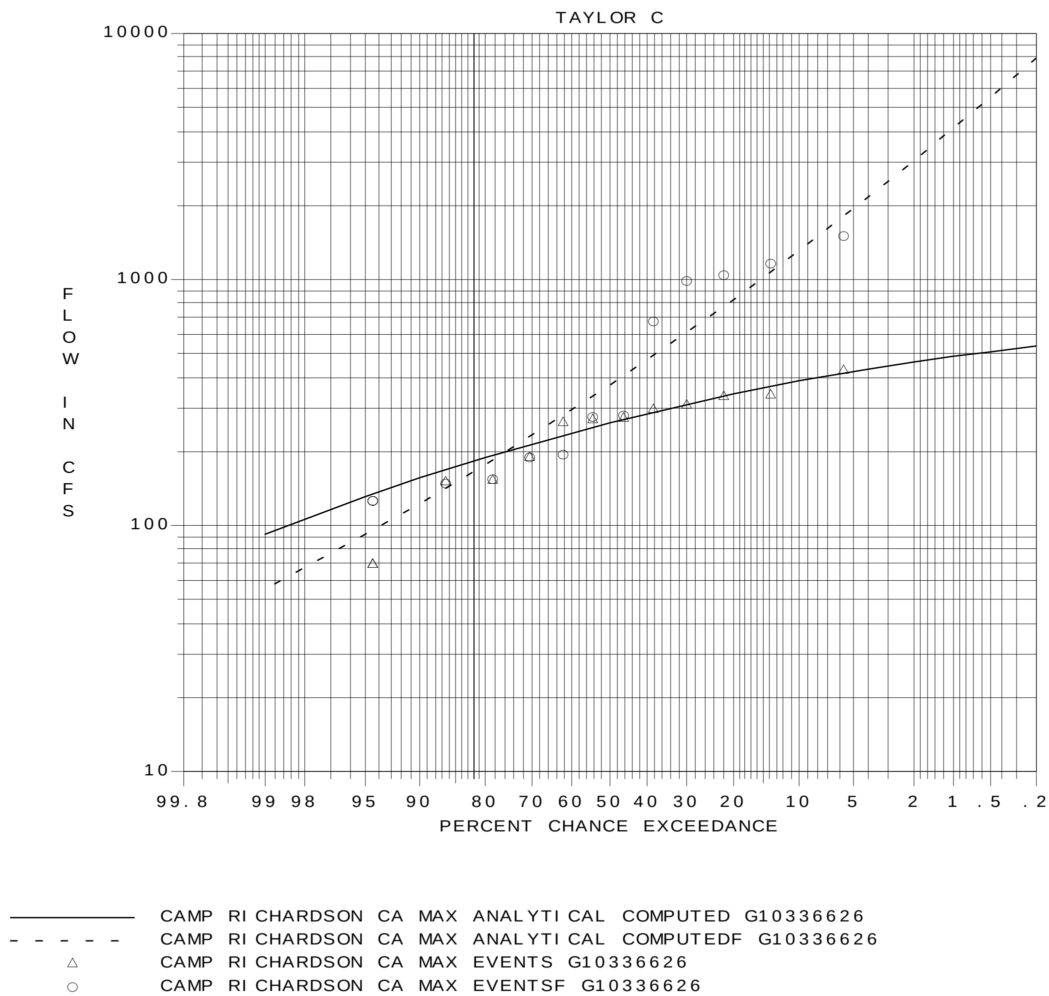

Figure 7.3: Split sample annual peak frequency analysis, Taylor Creek near Camp Richardson, USGS gage 10336626

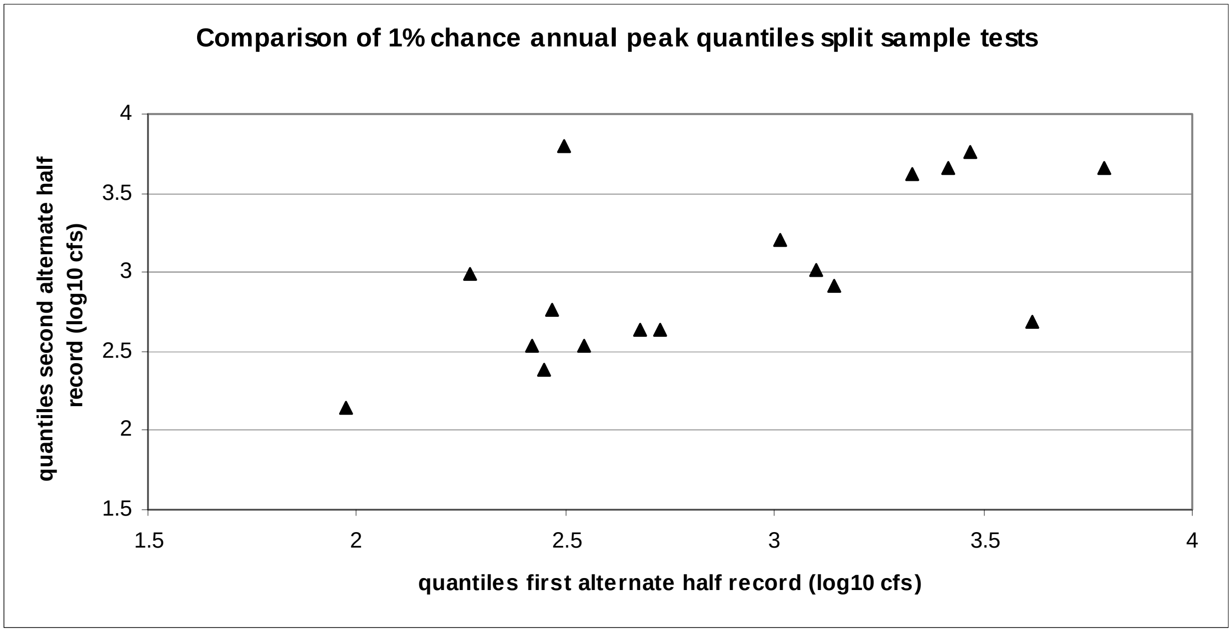

Figure 7.4: Comparison of 1% chance peak annual quantiles for split sample tests at selected regional gages

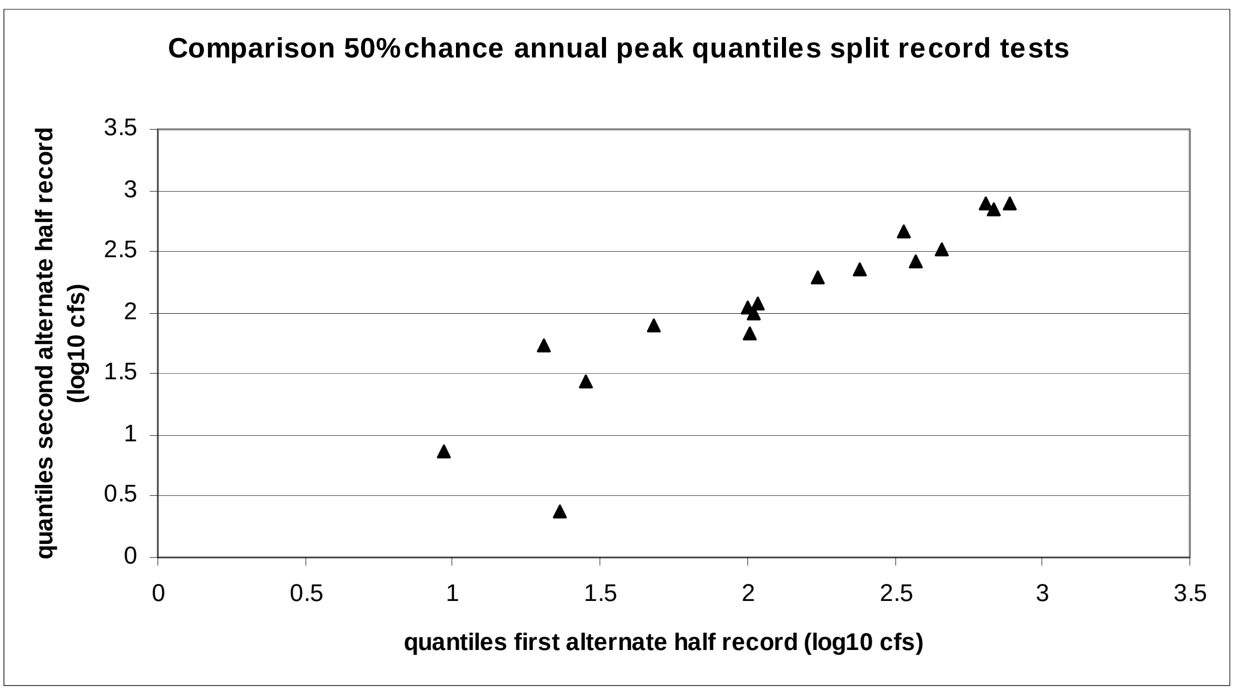

Figure 7.5: Comparison of 50% chance peak annual quantiles for split sample tests at selected regional gages

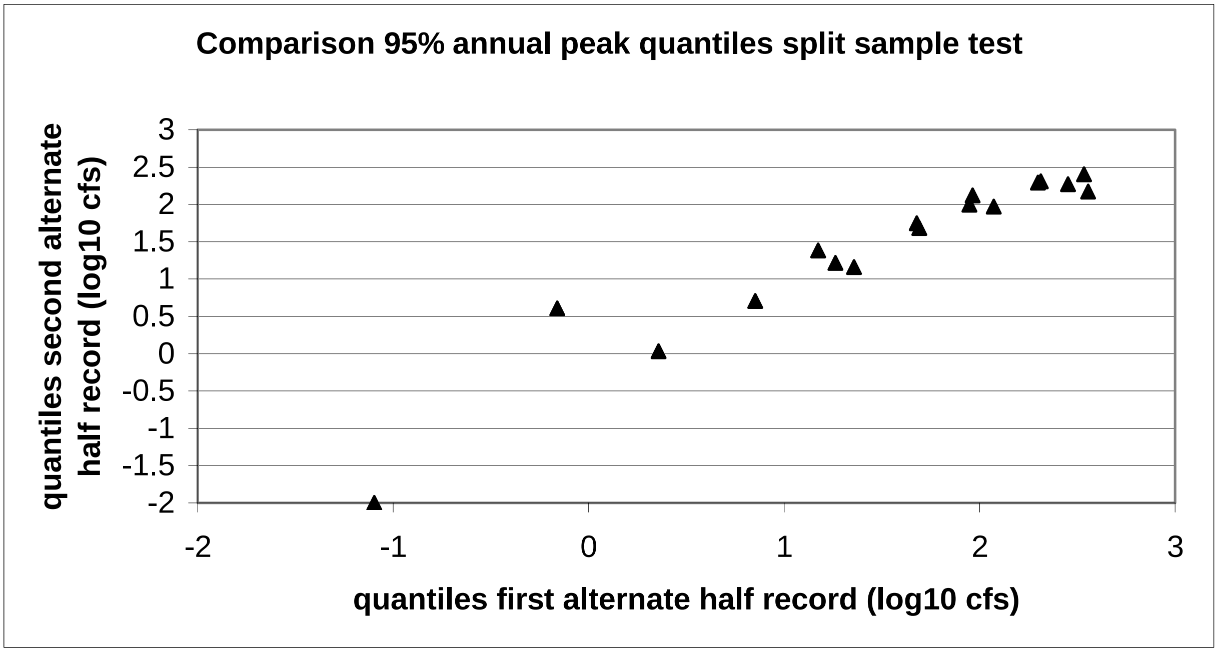

Figure 7.6: Comparison of 1% chance peak annual quantiles for split sample tests at selected regional gages

Table 7.2: Generalized least squares regression coefficients for independent variables obtained from first and second sets of split data

	first set of data				second set of data			
[1]P	[2]constant	area	elevation	map	[2]constant	area	elevation	map
1%	9.6033	0.9384	-2.9165	2.2496	12.8359	1.1241	-3.5952	1.6661
50%	-2.6296	0.8871		2.3278	-3.0568	1.0288		2.4999
95%	-5.3797	1.4317		3.3677	-5.7212	1.4753		3.5108

[1]Exceedance frequency
[2]Generalized least squares regression coefficients

Table 7.3: Average fraction prediction difference of selected quantiles at split sample test gages

Exceedance frequency	average prediction difference (%)
1%	1.0
50%	1.0
95%	-13.0

Table 7.4: Period of record implemented in split sample testing

gage	[1]systematic record	[2]95%	50%	1%
10265200	19	19	19	19
10265700	26	26	26	26
10267000	29	29	29	29
10276000	31	31	31	31
10291500	16	16	16	30
10292000	11	11	11	11
10299100	9	9	9	9
10302010	11	11	11	11
10304500	13	13	13	13
10310000	43	49	44	80
10310500	22	22	22	42
10311450	17	17	17	17
10336600	13	13	13	13
10336610	12	13	12	38
10336626	12	12	12	12
10336730	9	9	9	22
10343500	24	24	23	41
total years	317	324	317	444

[1]Half gage record length used to in split sample test
[2]Effective historic record length for first set of split sample data as a function of exceedance probability, exceeds systematic when 1997 event present in record

Table 7.5: Comparison of predicted and estimate error in split sample testing

p	[1]se	[1]se_w	[3]R^2	[4]avp	[5]se_w
1%	0.22	0.21	0.82	0.19	0.37
50%	0.23	0.19	0.85	0.23	0.29
95%	0.46	0.39	0.80	0.35	0.59

[1]se, standard error of regression from first alternate sample half portion of gage data (log_{10} cfs)
[2]se_w, standard error adjust for period of record first alternate sample half portion of gage data (log_{10} cfs)
[3]R^2, standard error estimated from first alternate sample half portion of gage data
[4]avp, average prediction error first alternate sample half portion of gage data (log_{10} cfs)
[5]se_w, standard error adjust for period of record second alternate sample half portion of gage data (log_{10} cfs)

8. Volume duration frequency regional regression relationships

8.1. Volume duration frequency curves

A mixed distribution approach was taken to estimating the annual maximum frequency curves for the 1, 3, 7, 10, 15, 30 day durations. Separate Bulletin 17B analyses were performed for winter events, occurring between October 1 and April 15th, and spring-summer type events defined as occurring for the remaining portion of the year. The seasonal curves were then combined into an annual curve. Section 12, a summary appendix, provides the statistics for each season and the estimates of the frequency curves at each gage. Very minor smoothing at a particular gage was performed for the large exceedance probabilities to prevent intersection of the 1-day to 30day curves.

8.2. Regression relationships

The consistency of the regression predicted curves were ensured by developing OLS regressions between peak flow and 1day duration and 1-day duration and other durations. The regressions were separated in this way because the peak flows did not correlate as well with longer-duration quantiles as did the 1-day values. Tables 8.1 and 8.2 provides the results of the regression equations. **Note: the regression standard errors only indicate the degree of fit in relating various durations to the peak and 1day quantiles.** The prediction accuracy should be estimated based on the average prediction error shown for the peak discharge frequency curves (see table 6.11). For example application of the regression equations and the computation of prediction confidence limits see SPK (2005). Also, the application of these regressions should be restricted to the same drainage area characteristics as discussed for the peak flow regressions and as noted in the tables (also see section 6.8).

Table 8.1: Lake Tahoe Basin regression relationships between peak annual quantile and 1 day annual maximum (based on log-Pearson III estimates from gage analysis)

(Regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50 and not urban areas)

	0.99	0.95	0.9	0.8	0.5	0.2	0.1	0.04	0.02	0.01	0.002
[1]b	0.958596	0.990323	0.97329	0.979087	0.988666	0.978598	0.972665	0.973848	0.974342	0.978921	0.979076
a	0.048461	-0.015	0.010924	-0.01762	-0.08182	-0.1054	-0.10293	-0.10213	-0.09836	-0.09954	-0.09004
correlation	0.997605	0.998376	0.996842	0.99676	0.995927	0.99353	0.990794	0.986736	0.984563	0.982225	0.980661

$\log_{10}(Q_{1day}) = \mathbf{a} + \mathbf{b}[\log_{10}(Q_{peak})]$, where Q_{1day} is the 1day duration quantile (e.g., 1day 0.01 exceedance probability flow (cfs/day)) and Q_{peak} is the quantile for the annual maximum peak flow (cfs)

[1]see SPK 2005 for example applications

Table 8.2: Lake Tahoe Basin regression relationships between 1day quantile and other duration quantiles (based on log-Pearson III estimates from gage analysis

(Regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50 and not to urban areas)

[1]probability	[2]constants/correlation	3day	7day	10day	15day	30day
0.99	b	0.993308	0.99025	0.982075	0.96804	0.944451
	a	-0.01257	-0.03303	-0.04046	-0.05078	-0.07836
	correlation	1.000	0.998	0.998	0.997	0.995
0.95	b	0.985982	0.971634	0.962417	0.951393	0.934651
	a	-0.00648	-0.01888	-0.02567	-0.04312	-0.08261
	correlation	1.000	0.998	0.998	0.998	0.997
0.90	b	0.99923	0.987621	0.983363	0.975626	0.961631
	a	-0.03614	-0.06279	-0.07952	-0.10316	-0.14471
	correlation	0.999	0.998	0.998	0.998	0.997
0.80	b	0.996301	0.98171	0.973487	0.982671	0.968724
	a	-0.03775	-0.06061	-0.06864	-0.12775	-0.1647
	correlation	0.999	0.999	0.998	0.998	0.998
0.50	b	0.998265	0.987621	0.981524	0.978761	0.965912
	a	-0.05056	-0.08833	-0.10181	-0.13463	-0.16694
	correlation	1.000	0.999	0.999	0.998	0.998
0.20	b	0.99221	0.975531	0.970496	0.963261	0.950199
	a	-0.04933	-0.07828	-0.09573	-0.11602	-0.14453
	correlation	1.000	0.998	0.998	0.997	0.996
0.10	b	0.983585	0.958233	0.950237	0.939259	0.924215
	a	-0.03924	-0.05574	-0.06823	-0.07869	-0.10142
	correlation	0.999	0.997	0.996	0.995	0.994
0.04	b	0.970159	0.926978	0.911073	0.894943	0.875257
	a	-0.01914	-0.00588	-0.00369	-0.00217	-0.01318
	correlation	0.999	0.995	0.993	0.990	0.988
0.02	b	0.966892	0.906824	0.886033	0.86466	0.841265
	a	-0.012	0.029517	0.04166	0.055717	0.052658
	correlation	0.998	0.992	0.989	0.986	0.982
0.01	b	0.962746	0.884046	0.854176	0.831611	0.803941
	a	-0.00672	0.070869	0.106669	0.122217	0.128375
	correlation	0.998	0.994	0.999	0.999	0.999
0.002	b	0.976006	0.859373	0.819634	0.783623	0.744137
	a	-0.03389	0.118144	0.170341	0.221591	0.261264
	correlation	0.997	0.986	0.978	0.967	0.958

[1]Exceedance probability

[2]$\log_{10}(Q_{nday}) = \mathbf{a} + \mathbf{b}[\log_{10}(Q_{1day})]$, where Q_{nday} is the duration quantile (e.g., 3day 0.01 exceedance probability, cfs./day)) and Q_{1day} is the quantile for the 1day duration volume duration frequency curve (cfs/day), for example application see (SPK 2005)

9. Lake Tahoe Basin 7day low-flow frequency curve regional regression analysis

9.1. Introduction

The low-flow frequency analysis provided different challenges than the peak flow and volume duration frequency analysis both because of the data quality and distribution selection. The data quality was highly affected by diversions as described in section 2. The lack of quality data prevented a low-flow analysis for the regional gages. However there was enough data to perform the analysis for the Lake Tahoe Basin. The focus of the analysis was on the 7-day duration which has potential for some use in addressing regulatory problems (e.g., estimation of the 7day, 10 year flow).

Selection of the distribution to use for low-flow frequency analysis is always difficult given the overall non-linearity of the empirical distribution (i.e., frequency curve estimated using plotting positions) of the observed flows. Section 9.2 discusses the approach used to attempting to explain the observed frequencies of the data with a log-Pearson III distribution. Section 9.3 details the development of the low-flow regressions using this distribution.

9.2. Low-flow frequency analysis

Tables 9.1 and 9.2-9.3 provide both the statistics and quantiles for the log-Pearson III fit to the 7 day annual minimum flow values. The gages shown in these tables were selected because the flows are not affected by any water supply or hydro-power diversions. Figures 9.1-9.5 show that the fit of this distribution is generally very reasonable, at least for exceedance probabilities less than or equal to the 90% (90% exceedance probability is equivalent to a 10% cumulative probability or 10 year return interval). Consequently, these quantiles were judged to be adequate for developing regional low-flow relationships for Lake Tahoe Basin.

Table 9.1: 7-day low flow statistics log-Pearson III distribution

Watershed	USGS ID	mean	std dev	skew
GENERAL	10336645	0.195	0.1759	0.26
BLACKWOOD	10336660	-0.302	0.3458	-0.09
WARD	10336674	-0.156	0.2199	0.34
WARD	10336675	-0.764	0.596	-0.06
WARD	10336676	0.304	0.2473	0.22
INCLINE	103366993	0.153	0.3107	0.3
INCLINE	103366995	-0.061	0.3833	-0.12
INCLINE	10336700	-1.121	0.6559	-0.49
GLENBROOK	10336730	0.552	0.1412	0.47
LOGAN HOUSE	10336740	0.765	0.2261	0.26
EAGLE ROCK	103367592	0.945	0.2436	0.07
TROUT	10336770	-0.326	0.5277	-0.61
TROUT	10336775	-0.098	0.2719	-0.29
TROUT	10336780	-0.572	0.2028	-0.67

Table 9.2: Log-Pearson III low-flow frequency analysis

Watershed	USGS ID	years	99	95	90	80	50	20
GENERAL	10336645	22	0.24	0.32	0.37	0.45	0.68	1.06
BLACKWOOD	10336660	42	0.66	0.83	0.94	1.11	1.54	2.19
WARD	10336674	7	0.07	0.11	0.14	0.18	0.28	0.4
WARD	10336675	10	0.16	0.27	0.35	0.48	0.82	1.36
WARD	10336676	27	0.02	0.05	0.09	0.18	0.53	1.34
INCLINE	103366993	12	0.1	0.2	0.28	0.42	0.89	1.84
INCLINE	103366995	12	0.31	0.47	0.58	0.77	1.37	2.56
INCLINE	10336700	18	0.59	0.82	0.99	1.24	1.97	3.23
GLENBROOK	10336730	18	0.01	0.02	0.03	0.05	0.17	0.55
LOGAN HOUSE	10336740	18	0.001	0.01	0.01	0.02	0.09	0.28
EAGLE ROCK	103367592	10	0.07	0.13	0.18	0.26	0.51	0.98
TROUT	10336770	12	1.88	2.19	2.4	2.7	3.47	4.64
TROUT	10336775	12	1.91	2.57	3.03	3.74	5.69	8.95
TROUT	10336780	42	2.46	3.54	4.31	5.48	8.75	14.09

Table 9.3: low-flow frequency analysis

Watershed	USGS ID	years	10	4	2	1	0.5	0.2
GENERAL	10336645	22	1.36	1.79	2.16	2.57	3.03	3.71
BLACKWOOD	10336660	42	2.66	3.3	3.81	4.34	4.91	5.72
WARD	10336674	7	0.47	0.54	0.59	0.63	0.67	0.71
WARD	10336675	10	1.74	2.24	2.61	2.99	3.38	3.89
WARD	10336676	27	2.03	3.02	3.8	4.61	5.44	6.53
INCLINE	103366993	12	2.66	3.93	5.03	6.27	7.65	9.71
INCLINE	103366995	12	3.63	5.33	6.9	8.75	10.93	14.41
INCLINE	10336700	18	4.23	5.7	6.94	8.32	9.84	12.12
GLENBROOK	10336730	18	0.99	1.85	2.75	3.93	5.44	8.04
LOGAN HOUSE	10336740	18	0.48	0.81	1.12	1.47	1.86	2.43
EAGLE ROCK	103367592	10	1.37	1.96	2.46	3.01	3.62	4.51
TROUT	10336770	12	5.48	6.62	7.52	8.49	9.51	10.97
TROUT	10336775	12	11.49	15.14	18.19	21.54	25.23	30.67
TROUT	10336780	42	18.15	23.83	28.46	33.43	38.76	46.42

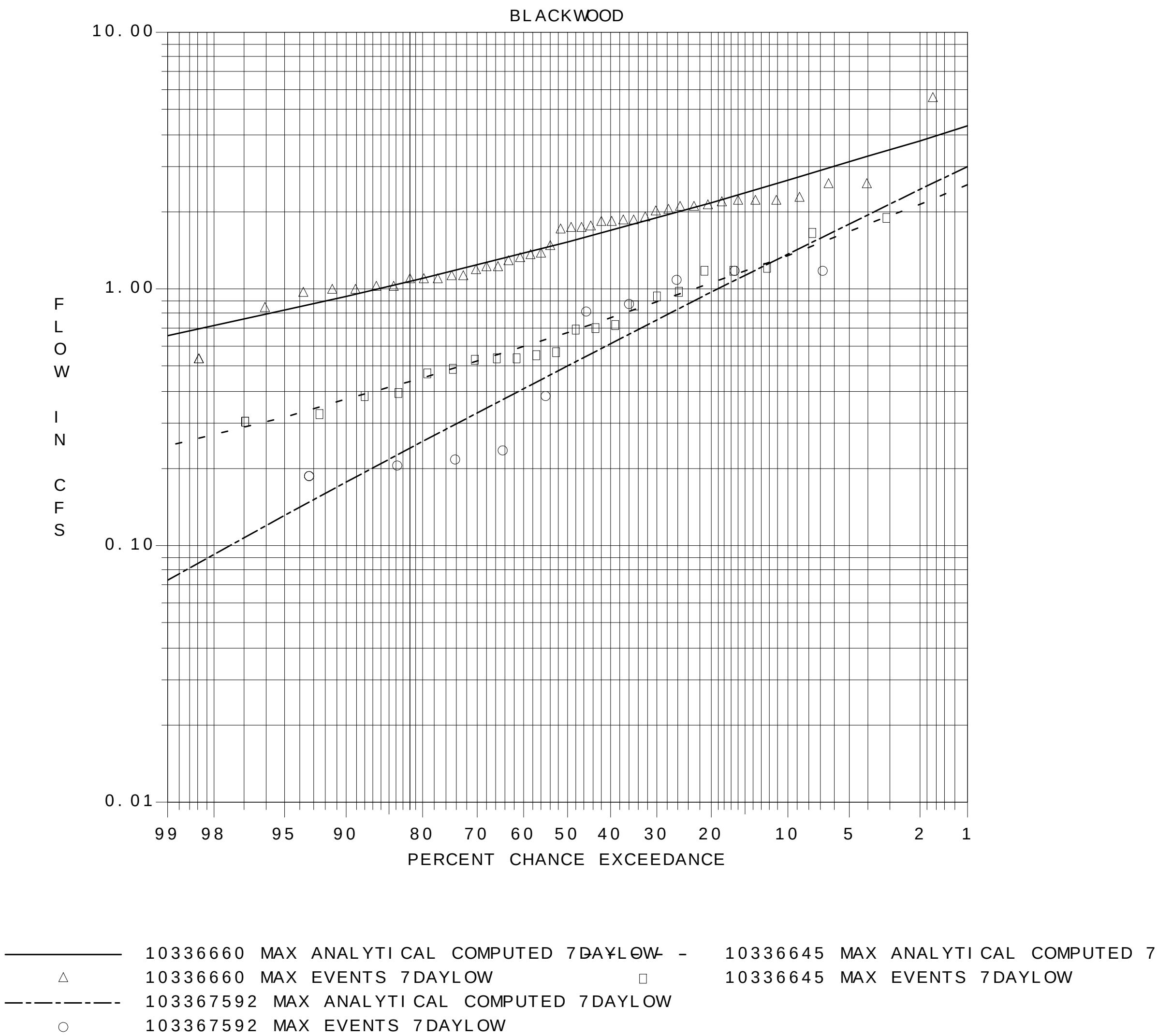

Figure 9.1: 7day volume low-flow frequency curves, USGS gages 10336660, 103367592, 10336645

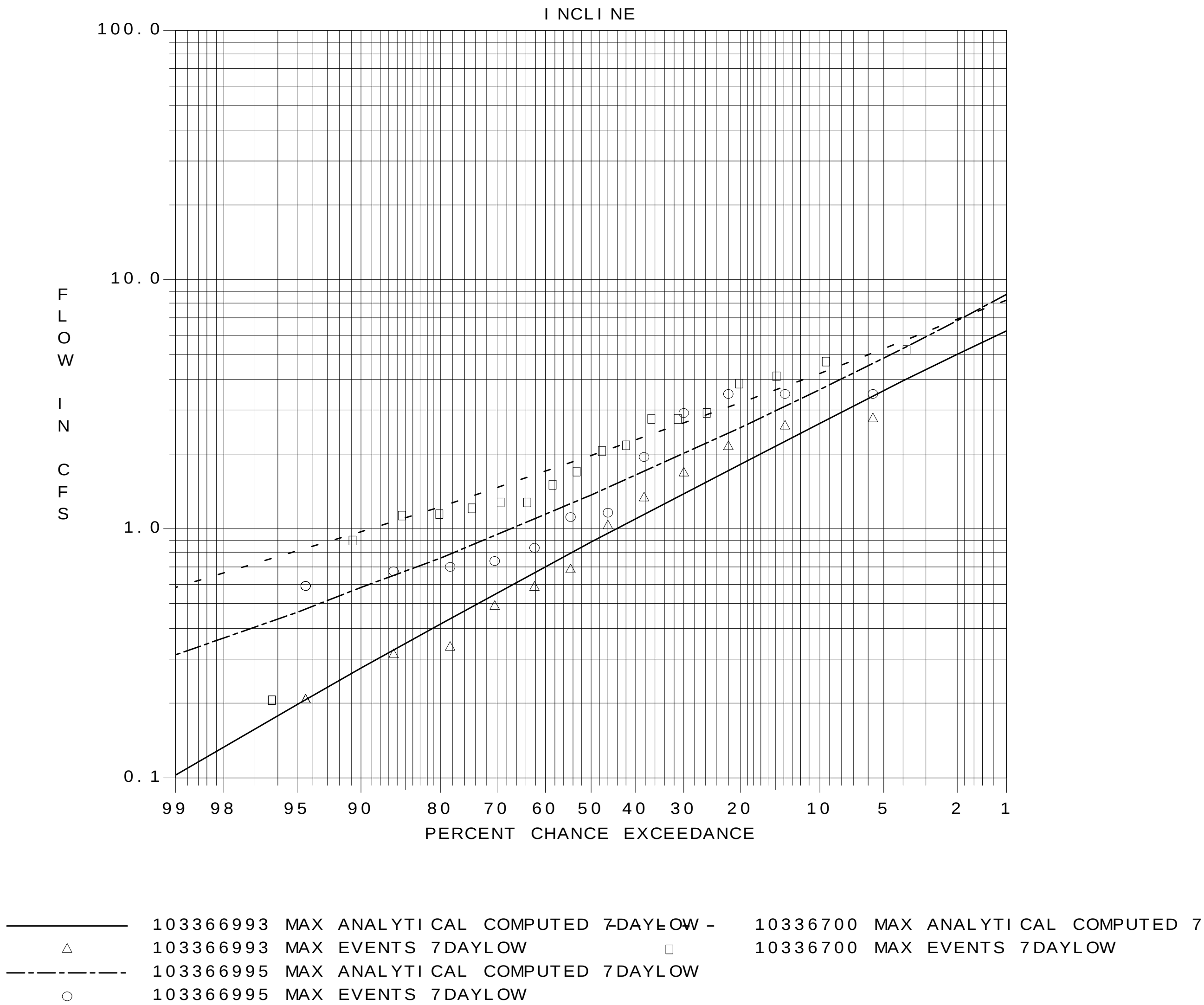

Figure 9.2: 7day volume low-flow frequency curves, Incline Creek USGS gages 103366993, 10336700, 103366995

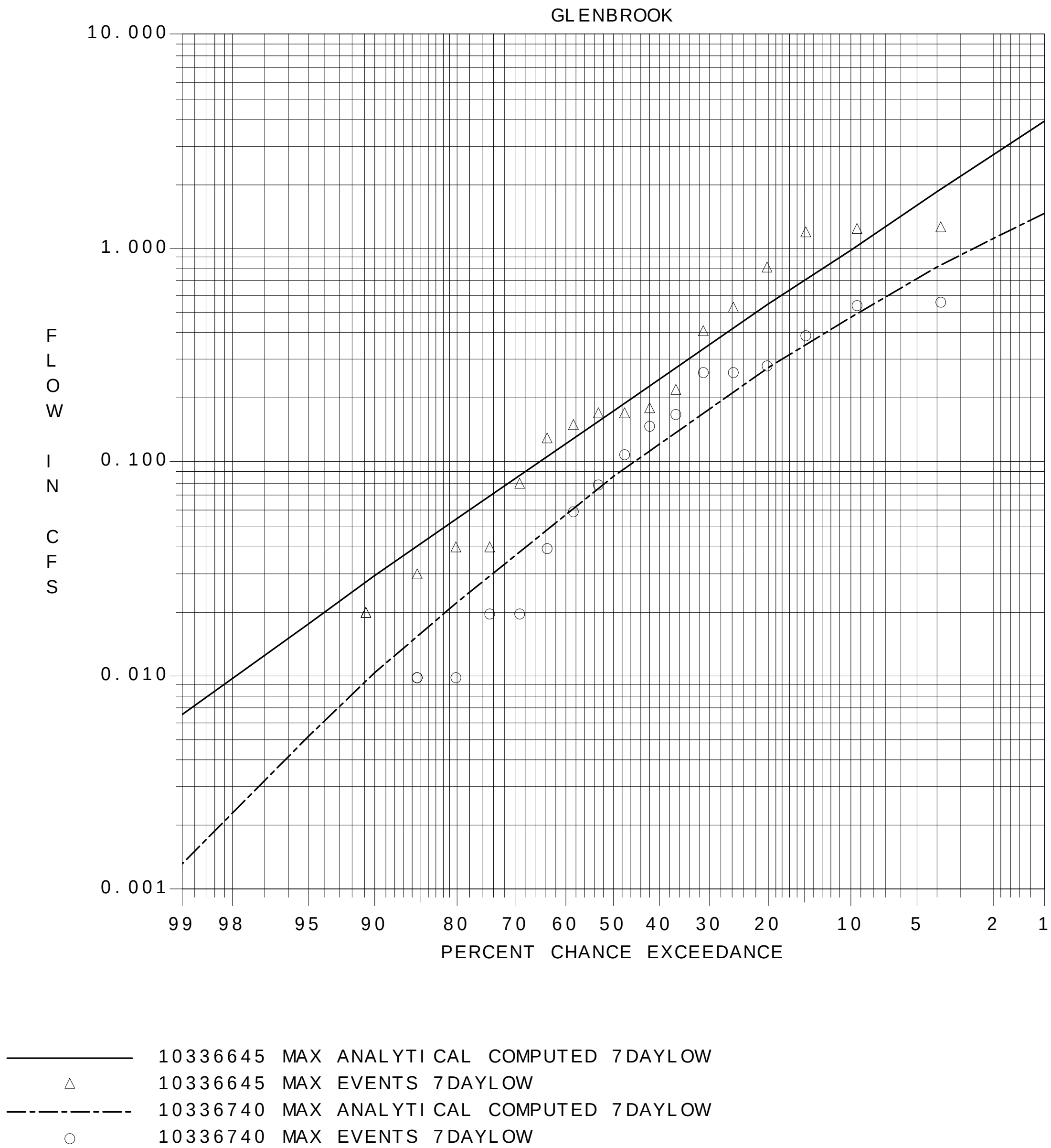

Figure 9.3: 7day volume low-flow frequency curves, USGS gages 10336645, 10336740

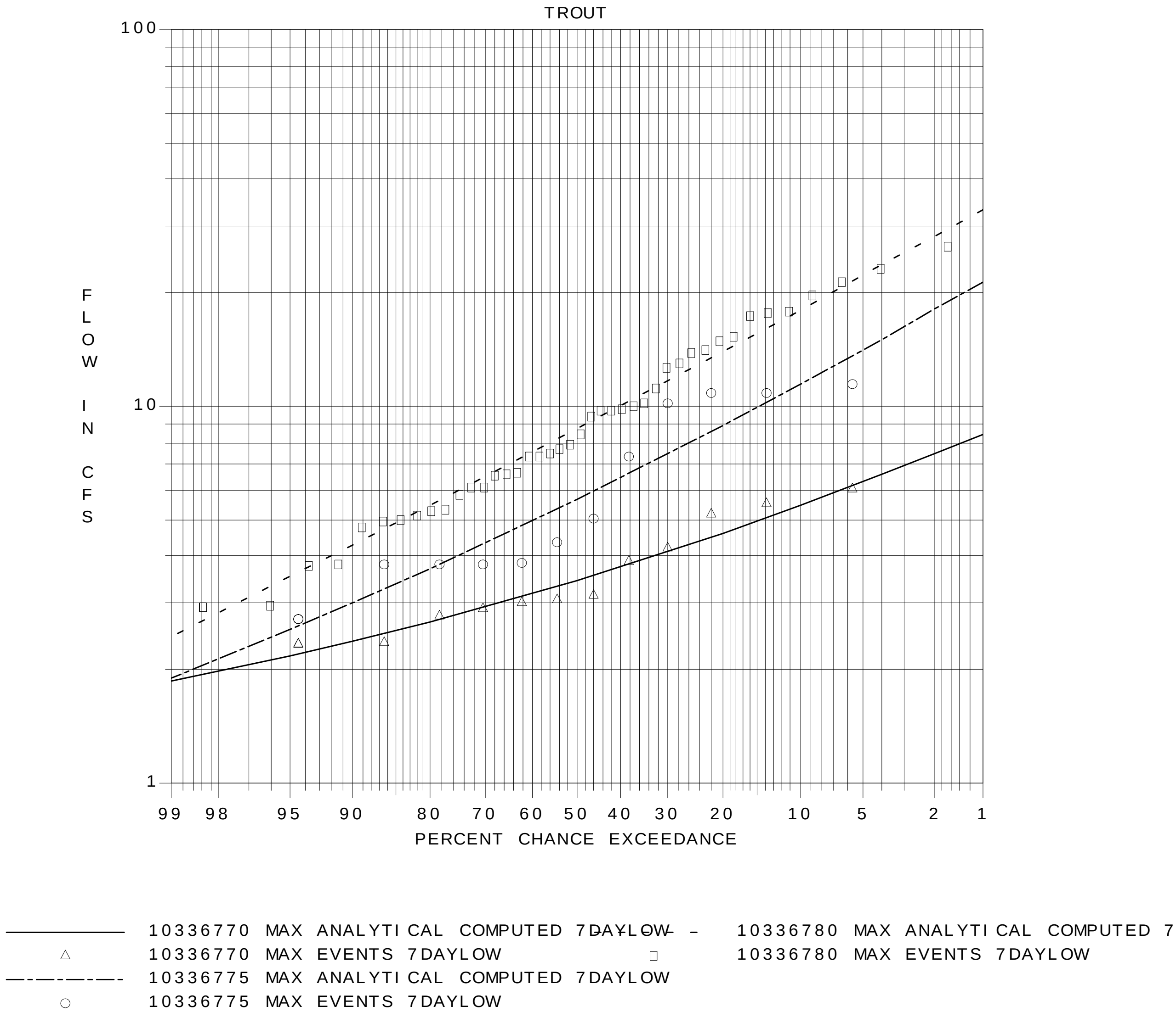

Figure 9.4: 7day volume low-flow frequency curves, Trout Creek USGS gages 10336770, 10336775, 10336780

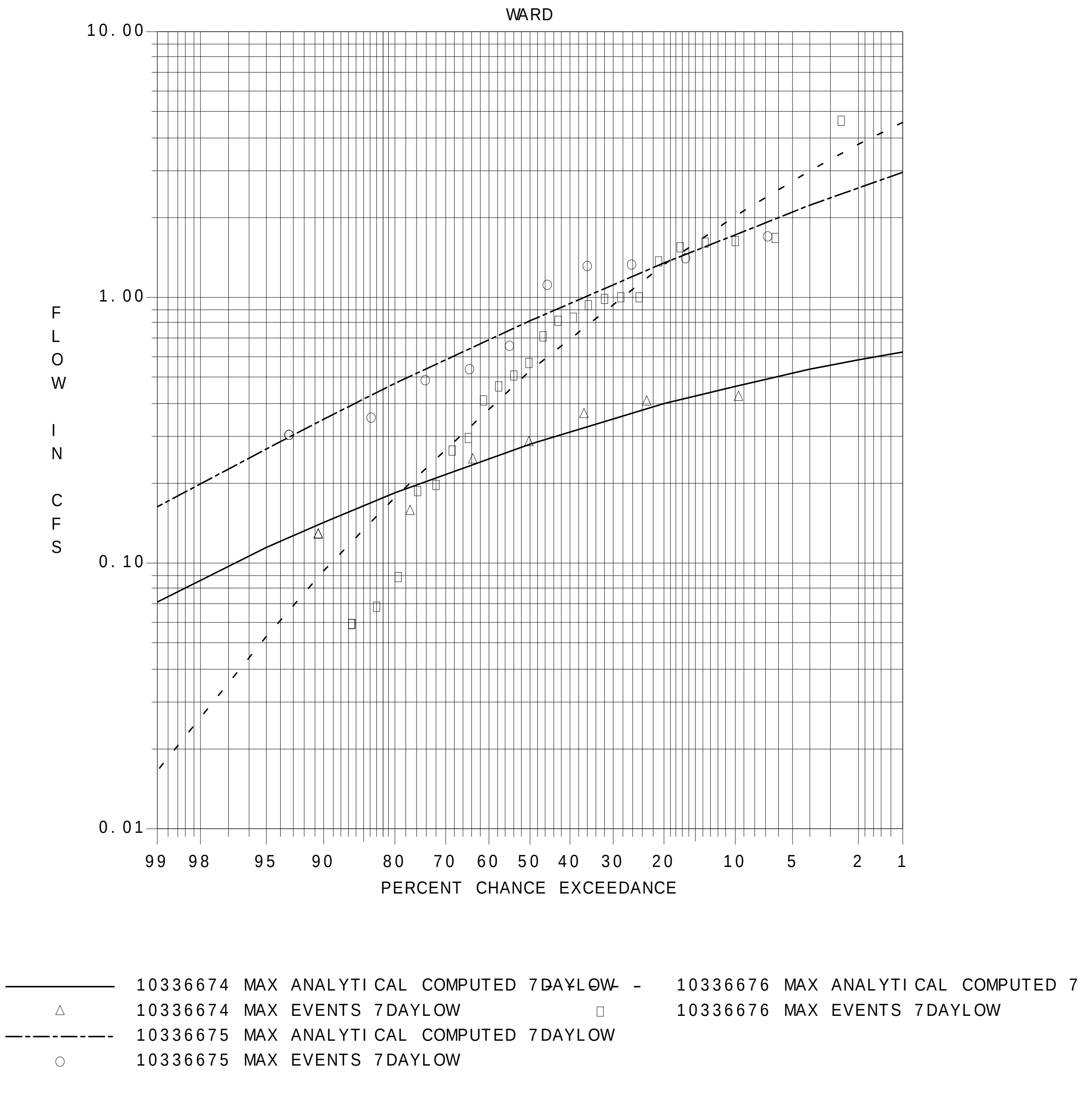

Figure 9.5: 7day volume low-flow frequency curves, Ward Creek USGS gages 10336674, 10336675, 10336676

9.3. Low-flow regression equations

Regression relations were developed for all possible combinations of log-transformed independent parameters described in section 2. The regression focused on these variables based on recent research by Kroll, et al., 2004, which found that meteorological characteristics were important in developing regional regressions for low-flow; and interestingly; nears surface soil characteristics were not significant in developing these relationships.

Ordinary least squares were used to develop the low-flow frequency curves given limitations of the scope of the study. Error measures provided for the regression will be only approximate given that the residual distribution will not correspond to the ideal estimation requirements of ordinary least squares.

Table 9.4 summarizes the ordinary least squares regression relationships found to be statistically most significant in explaining the low-flow quantiles estimated for gages described in the previous section (see section 11, technical appendix for further discussion). The best regressions as judged by the standard error involved annual mean snowfall. However, regressions using only drainage area and mean annual temperature are recommended because the predictions are almost as accurate without requiring estimation of snowfall. The regression equations should be restricted to the range of data employed in the analysis. Generally speaking this means the regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Highway 50 at Meyers or to urban areas.

Example applications of the regressions can be found in SPK (2005). Figures 9.6-9.9 provide examples of the goodness-of-fit of these regression relationships.

Table 9.4: 7day low flow regional regression relationship[1]

(Regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Meyers at Highway 50 or to urban areas)

[2]Probability	b_0	[3]area (b_1)	[4]snowfall (b_2)	[5]temperature (b_3)	[6]R^2	[7]SE
Recommended regression						
0.01	133.84415	0.68033		-83.20121	0.77	0.46
0.05	107.53622	0.58155		-66.80492	0.80	0.35
0.10	106.50728	0.57185		-66.10442	0.82	0.32
0.20	97.14648	0.54907		-60.24327	0.87	0.27
0.50	74.74878	0.50574		-46.26403	0.86	0.23
0.80	57.96734	0.47266		-35.75592	0.78	0.25
0.90	50.49741	0.45584		-31.06690	0.71	0.27
Best regression						
0.20	111.07000	0.68248	-0.86005	-67.65282	0.86	0.26
0.50	92.88154	0.67949	-1.12005	-55.91357	0.90	0.18
0.80	80.95735	0.69295	-1.42008	-47.99028	0.89	0.16
0.90	76.48834	0.70488	-1.60545	-44.89824	0.88	0.16

[1] $\log_{10}(Q_p) = b_0 + b_1(\log_{10}(\text{area})) + b_2(\log_{10}(\text{snowfall})) + b_3(\log_{10}(\text{temperature})$, Q_p is the flow (cfs) for cumulative (non-exceedance probability), see SPK (2005) for example application
[2] cumalive probability (non-exceedance), e.g., 0.10 is the 10year return interval for the 7day low flow
[3] regression coefficient for area (square miles)
[4] regression coefficient for watershed average mean annual snowfall (inches)
[5] regression coefficient for watershed average mean annual temperature (^{o}F)
[6] adjusted multiple coefficient of determination (log units)
[7] standard error (log-unit)

Examination of the figures comparing observed versus predicted quantiles certainly does cause some concern that the Trout Creek Basins (the largest magnitude flows for each exceedance probability) might cause some undue influence on the overall regression; i.e., that the regression is not relevant to smaller drainage area basins because of the influence of these large basins. Leverage statistics (see section 11, the technical appendix) indicate that there is some potential for the larger Trout Creek Basins to be unusually influential on the regression.

The overall importance of the Trout Creek Basins was tested by comparing these regressions (2 and 3 parameter regressions using the independent variables shown in Table 9.4) with a regression not using these basins. As can be seen from figure 9.10, the effect is not large on the 7 day 0.10 probability regression. Consequently, including the Trout Creek Basins is likely beneficial for application over the full range of drainage areas used in developing the regression equation.

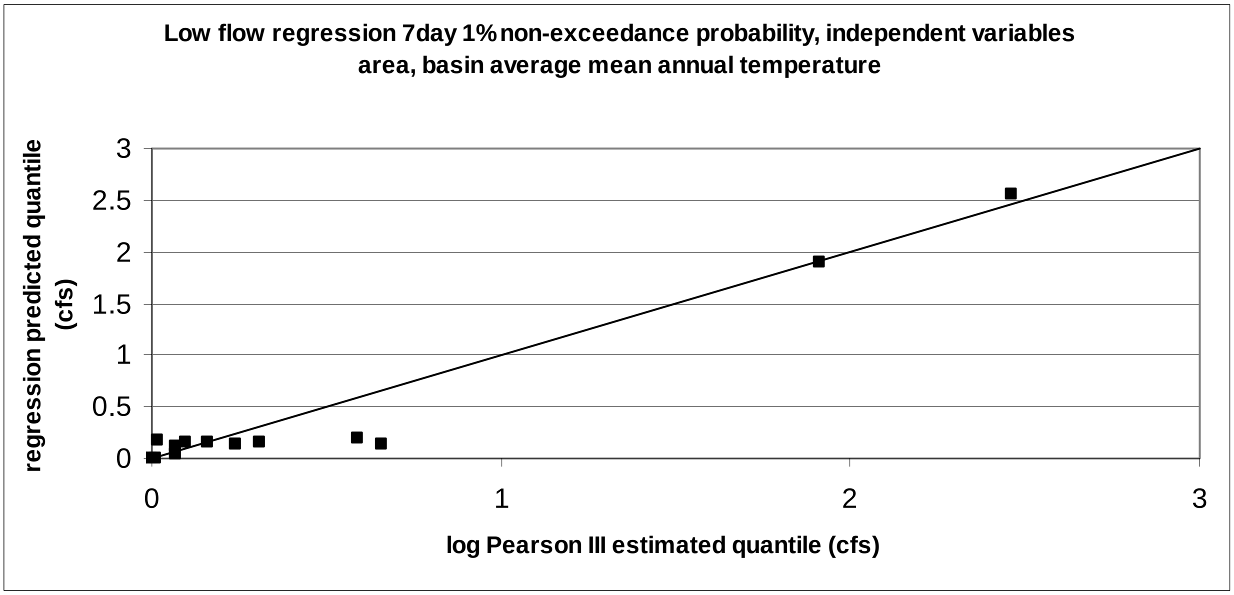

Fig 9.6: Comparison of observed and regression predicted 7day 1% non-exceedance low flow using drainage area and basin mean annual temperature

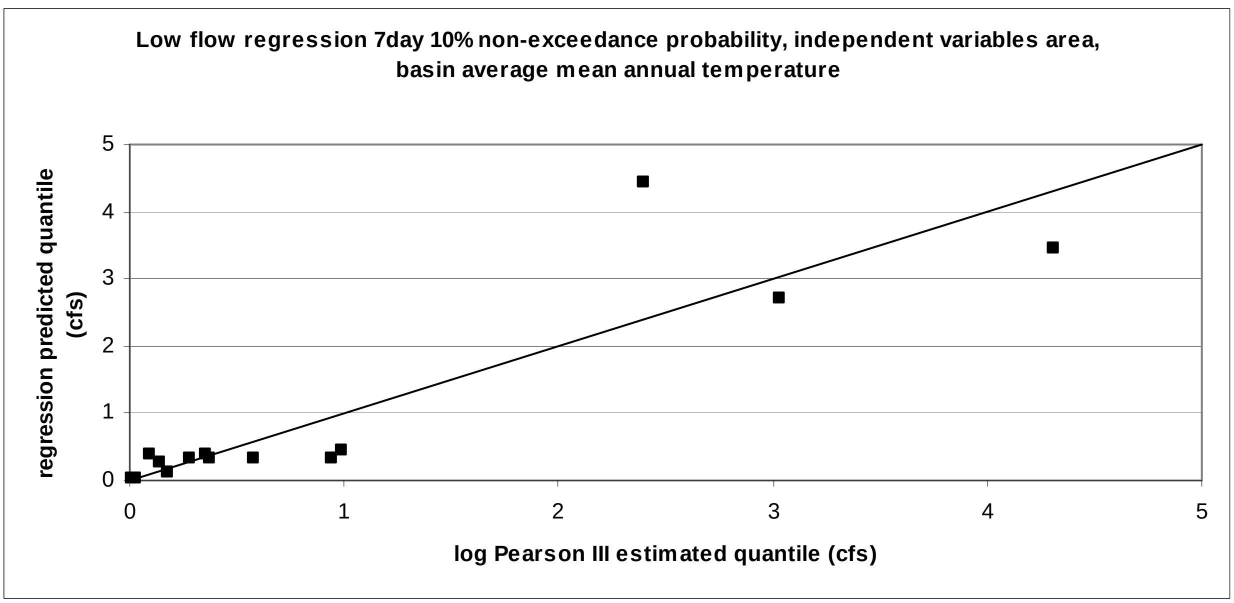

Fig 9.7: Comparison of observed and regression predicted 7day 10% non-exceedance low flow using drainage area and basin mean annual temperature

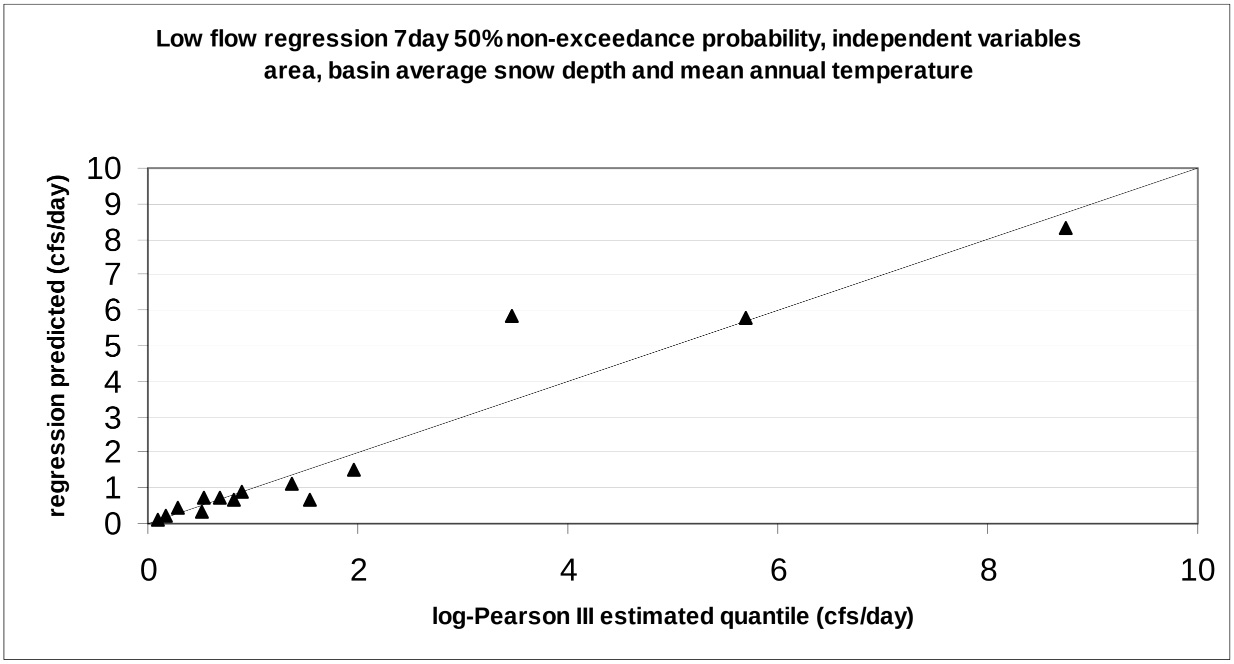

Fig 9.8: Comparison of observed and regression predicted 7day 50% non-exceedance low flow using drainage area, basin average total snowfall and basin mean annual temperature

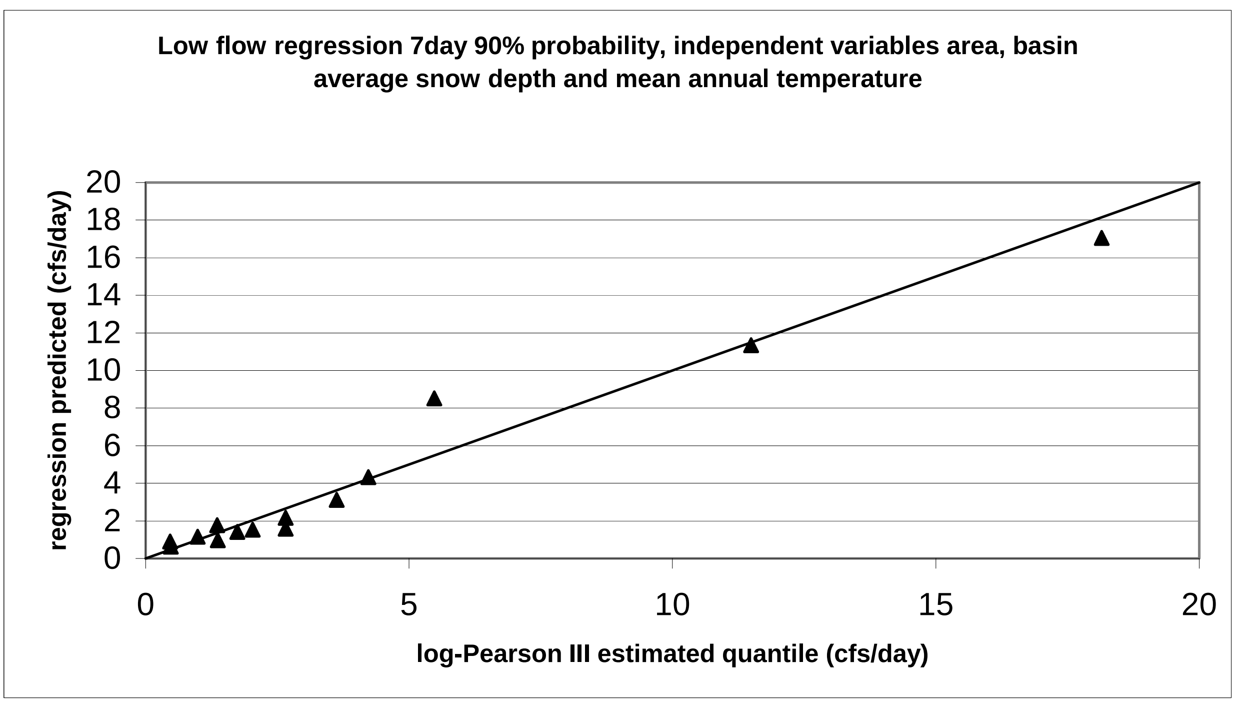

Fig 9.9: Comparison of observed and regression predicted 7day 90% non-exceedance low flow using drainage area, basin average total snowfall and basin mean annual temperature

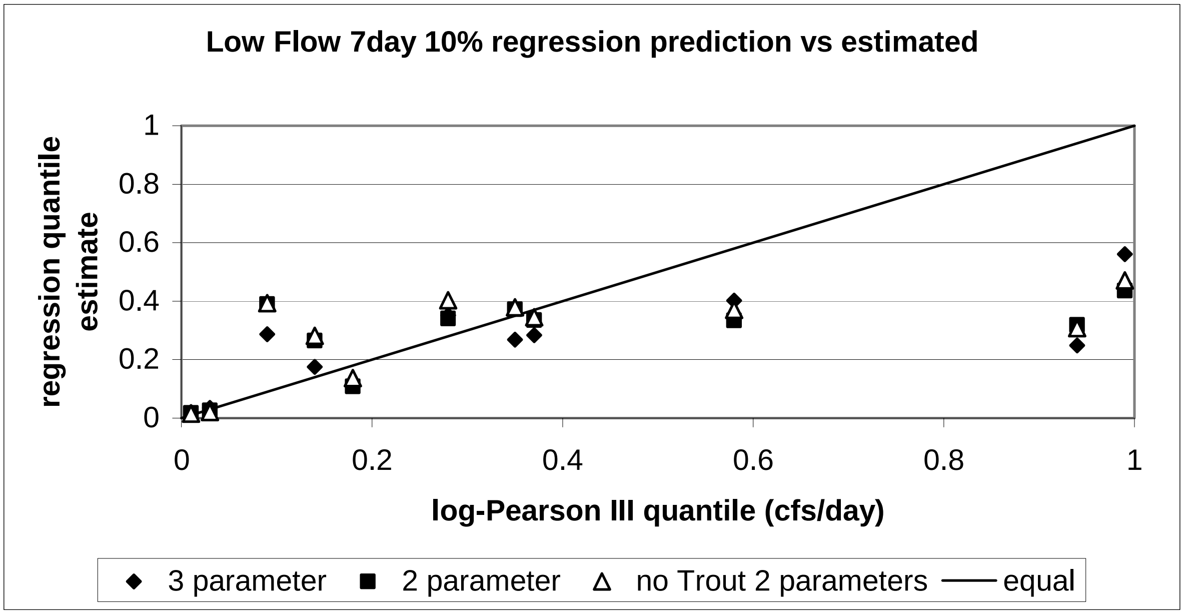

Fig 9.10: Comparison of regression predicted 7day 10% non-exceedance low flow using various number of parameters, and excluding the Trout Creek Basins

10. Lake Tahoe Basin regional flow duration regression relationships

10.1. Flow duration estimates

Obtaining flow-duration curves presents a different estimation problem than in obtaining the peak, volume duration or low-flow frequency curves. In estimating flow-duration curves probability distributions are not used, rather the empirical frequencies are employed (see section 3). Estimates for the regressions were obtained by interpolating between the empirical frequencies using cubic spline interpolation.

The flow-duration analysis was performed for the same Lake Tahoe Basin gages as in the previous low-flow analysis as shown in Table 10.1. These gages have a period of record unaffected by water supply diversions.

Table 10.1: Spline interpolated estimates of 1day flow-duration

Watershed	USGS ID	[1]99%	95%	90%	50%	10%	5%	1%
GENERAL	10336645	[2]0.5	0.7	0.9	3.6	53.0	86.4	156.1
BLACKWOOD	10336660	1.2	1.8	2.2	10.0	106.4	159.0	287.0
WARD	10336674	0.3	0.4	0.5	4.3	58.3	90.0	149.8
WARD	10336675	0.5	0.7	1.2	6.3	93.5	138.6	214.3
WARD	10336676	0.3	0.5	1.0	7.1	78.5	124.0	224.3
INCLINE	103366993	0.4	0.5	0.7	2.9	12.2	18.9	27.2
INCLINE	103366995	0.9	1.0	1.1	3.8	17.8	24.5	34.6
INCLINE	10336700	0.9	1.6	2.0	5.2	19.5	27.2	42.4
GLENBROOK	10336730	0.2	0.3	0.4	1.1	4.3	7.4	13.4
LOGAN HOUSE	10336740	0.2	0.3	0.3	0.5	1.6	2.6	4.7
EAGLE ROCK	103367592	0.3	0.4	0.4	0.7	1.4	1.5	1.7
TROUT	10336770	2.4	2.9	3.2	6.3	29.1	49.3	76.8
TROUT	10336775	3.7	4.7	5.2	14.4	70.7	103.1	151.3
TROUT	10336780	4.8	7.1	9.1	23.3	82.3	137.0	279.4

[1]Exceedance probability (percent of time exceeded)
[2]Flow (cfs/day)

10.2. Regression relationships

As in the low-flow analysis, ordinary least squares was used to develop the low-flow frequency curves given limitations on the scope of the study. Error measures provided for the regression will be only approximate given that the residual distribution will not correspond to the ideal estimation requirements of ordinary least squares. Tables 10.2 and 10.3 summarize the statistically significant relationships found (see technical appendix for a further discussion). The regression equations should be restricted to the range of data employed in the analysis. Generally speaking this means the regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Highway 50 at Meyers or to urban areas. Figures 10.1-10.6 proved a comparison of the observed (frequency estimates at the gage) versus regression prediction to show goodness-of-fit

Note that in Figure 10.4, a comparison is made of regression using mean annual snowfall and precipitation for the 50% flow duration exceeded. Mean total annual snowfall provides a marginally better regression; but practically speaking, the comparison shows that the difference is not very significant. Consequently, application of mean annual precipitation is recommended because it results in more consistent prediction of quantiles near the boundaries of the independent data, does not require the estimation of snowfall, and prediction accuracy does not suffer greatly.

Table 10.2: Lake Tahoe watersheds daily flow duration regression relationship parameters

(Regression equations should be limited to open land use drainage areas > 0.5 sq mi, basins where a significant portion of drainage area exceeds 7000 ft msl, should not be applied to areas draining to Upper Truckee River downstream of Highway 50 or to urban areas)

[5]Frequency exceeded (f)	[6]b_0	[1]area	[2]elevation	[3]MAT	[4]MAP
99%	-43.8641	0.927195	11.04962		
95%	-38.8409	0.945971	9.789445		
90%	-32.7125	0.970529	8.235106		
50%	32.85813	0.80133		-20.24583805	
[7]50%	-1.64067	0.89692			0.942848
10%	-4.21429	0.85337			3.011556
5%	-4.11273	0.889998			3.038292
1%	-3.97303	0.965017			3.042417

[1]drainage area (square miles)
[2]mean basin elevation (feet msl)
[3] watershed average mean annual temperature (^oF)
[4]watershed average mean annual precipitation
[5]annual frequency (percent of time exceeded)daily flow level (cfs/day) exceeded
[6]Flow duration curve regression, $\log_{10}(Q_f)=b_0 + b_1\log_{10}(\text{area})\ b_2\log_{10}(\text{elevation}) + b_3\log_{10}(\text{MAT})+ b_4\log_{10}(\text{MAP})$
[7]Recommend regression for 50% frequency exceeded flow although slightly better R^2 using MAT rather than MAP

Table 10.3: Lake Tahoe watersheds daily flow duration regression goodness of fit and prediction error

[1]Frequency exceeded	[2]Adjusted R^2	[3] standard error
99%	0.86	0.18
95%	0.87	0.18
90%	0.90	0.15
50%	0.91	0.15
	[4]0.87	0.18
10%	0.96	0.13
5%	0.96	0.13
1%	0.95	0.15

[1] annual frequency daily flow level (cfs/day) exceeded
[2]log regression multiple coefficient of determination (adjusted for degrees of freedom)
[3] standard error $\log_{10}$ units
[4]Recommend regression for 50% frequency exceeded flow although slightly better R^2 using MAT rather than MAP

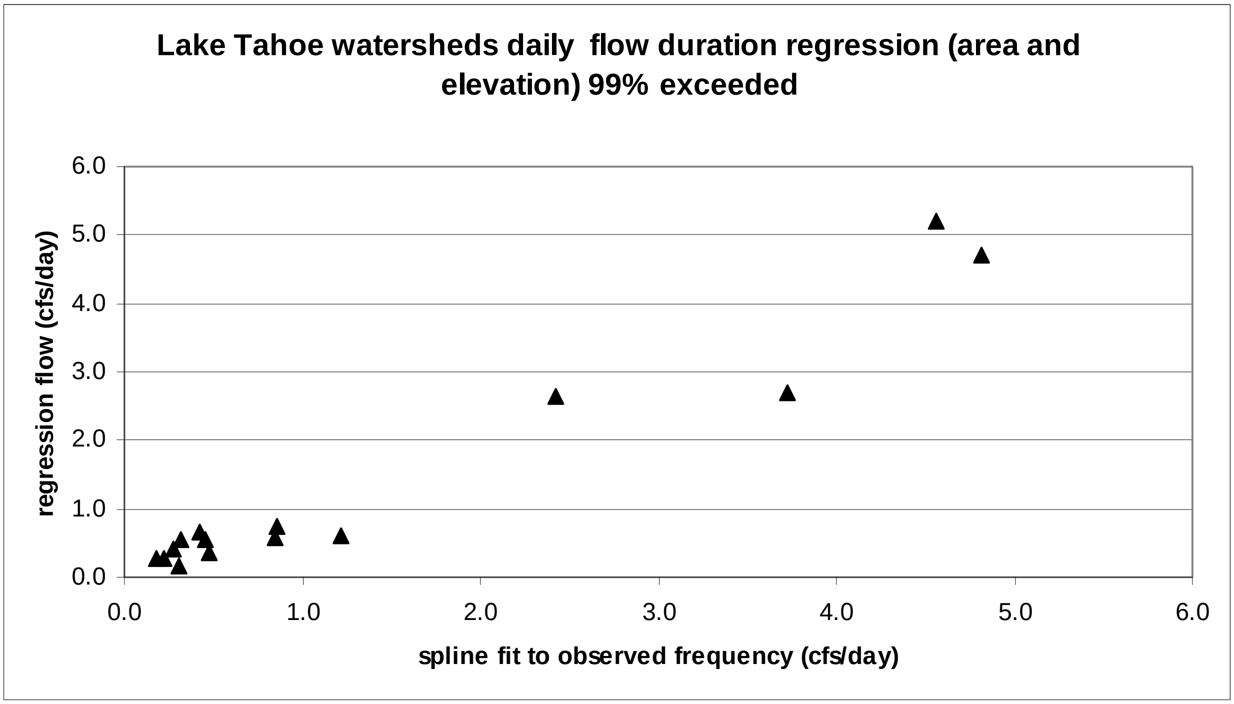

Figure 10.1: Observed versus regression predicted 99% flow-duration exceeded using area and elevation

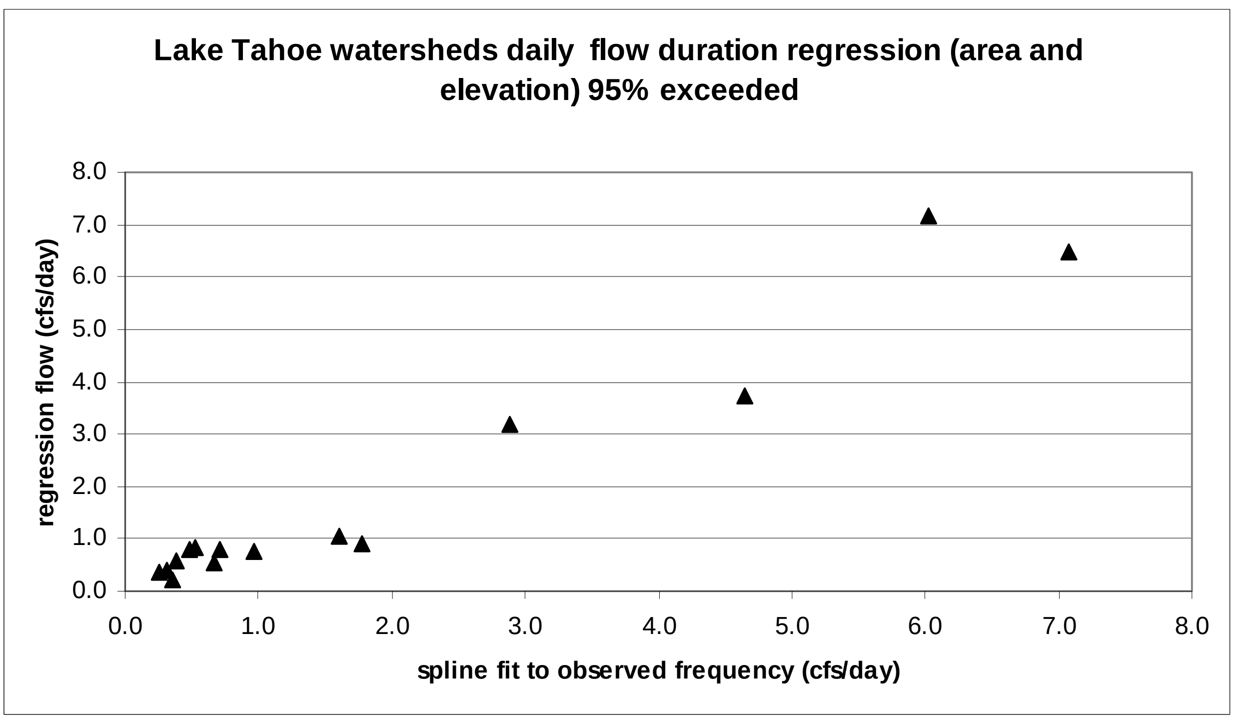

Figure 10.2: Observed versus regression predicted 95% flow-duration exceeded using area and elevation

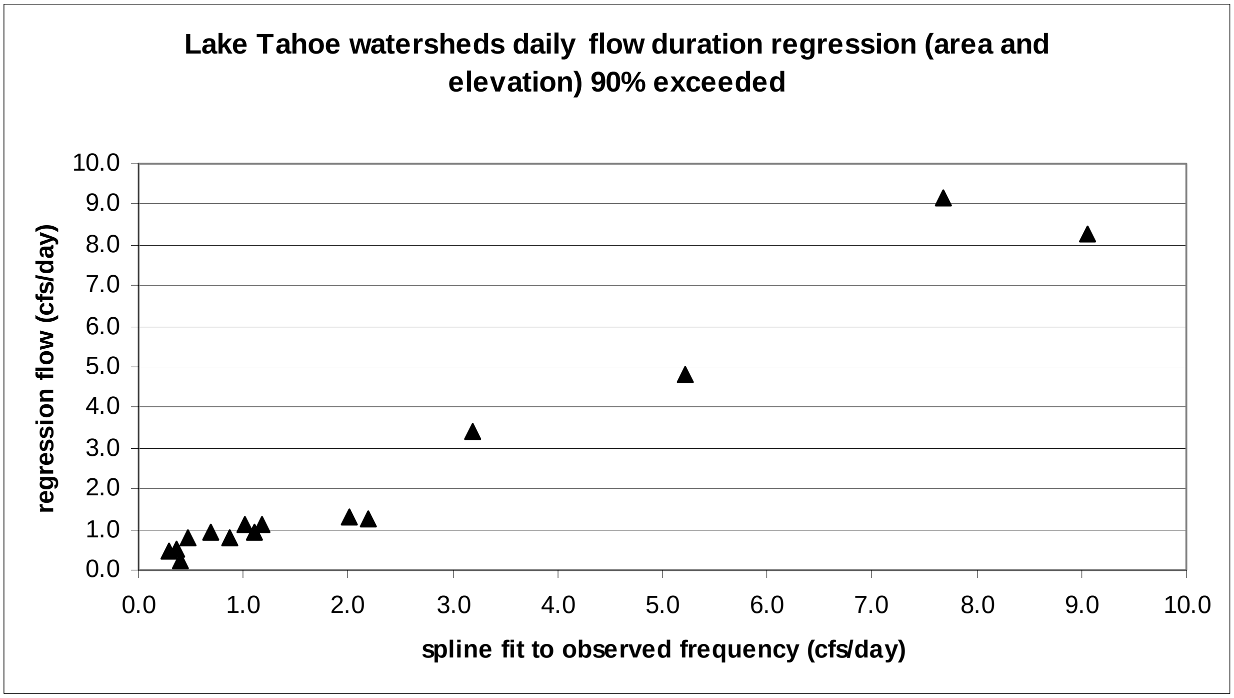

Figure 10.3: Observed versus regression predicted 90% flow-duration exceeded using area and elevation

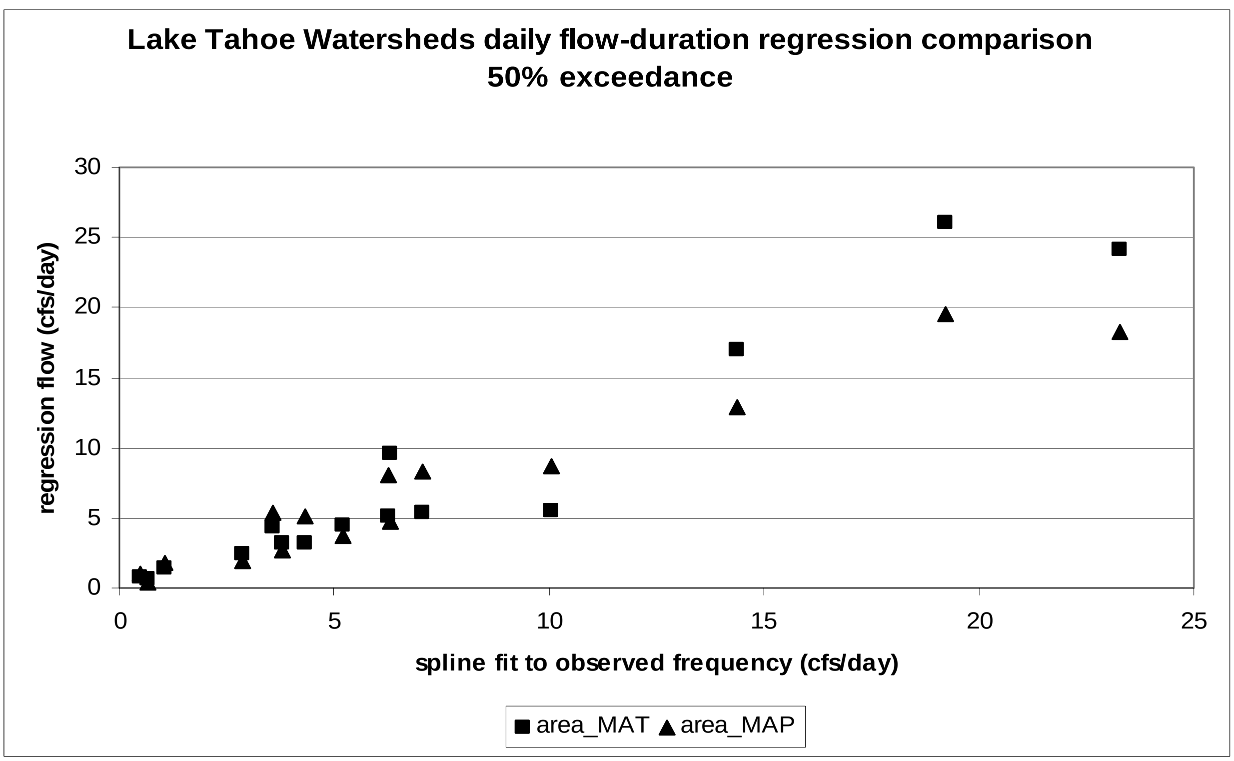

Figure 10.4: Observed versus regression predicted 50% flow-duration exceeded using area and comparing use of mean annual temperature versus mean annual precipitation

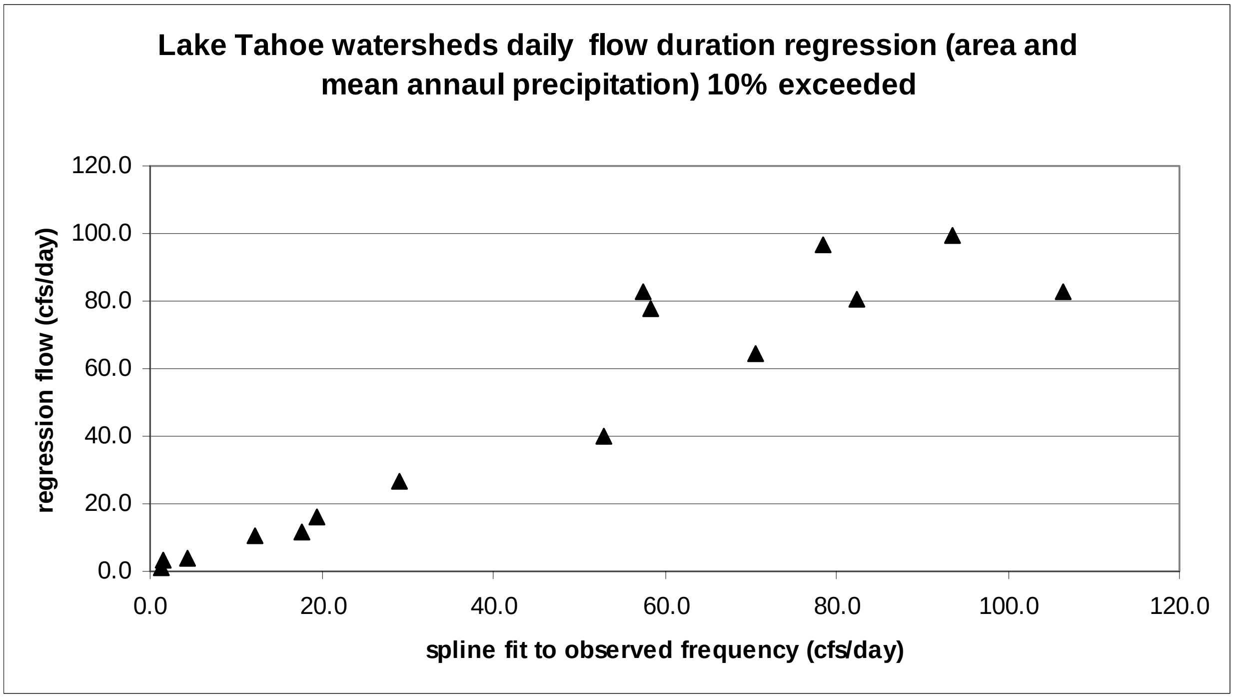

Figure 10.5: Observed versus regression predicted 10% flow-duration exceeded using area and mean annual precipitation

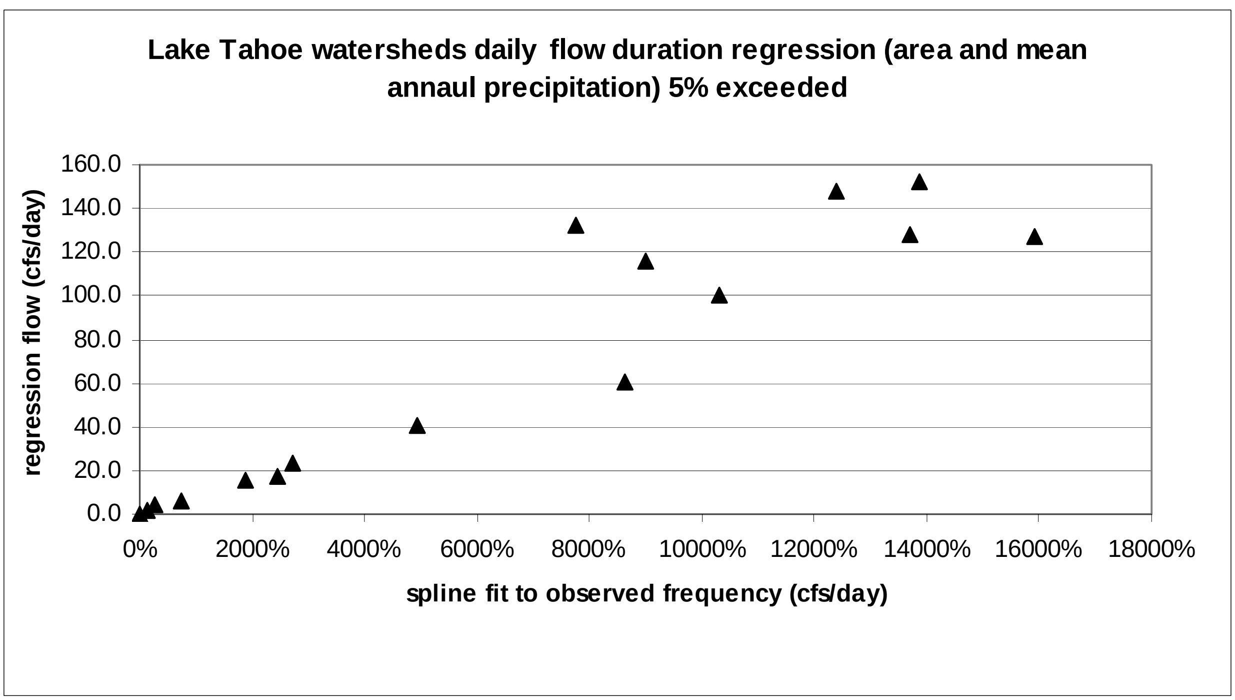

Figure 10.6: Observed versus regression predicted 5% flow-duration exceeded using area and mean annual precipitation

11. Appendix: Regression analysis technical appendix

11.1. Introduction

The purpose of this section is to describe the application of ordinary, weighted and generalized least squares (OLS, WLS, and GLS) to estimating the peak and high flow regional regression relationships. The general description of each regression theory, how each method differs, is given in section 11.2.

As is described in this section, the difference between methods results from different models for the regression residual errors. Estimating the covariance matrix for the GLS regression error model is a much more challenging problem for GLS than OLS as is discussed in section 11.3.

The magnitude of errors considered in application of GLS is partly a function of the gage record length. This presents a problem for this study because historic information was used to augment the period of record when estimating maximum flow quantiles. Section 11.4 discusses how an effective record length was computed given the application of historic information.

Besides the statistical significance, identifying influential data points, i.e., points that have unusually large influence on estimating regression parameters and of points that result in too great an extrapolation when using the regression for prediction. The statistical concept of leverage is used to identify these data points as is described in section 11.5

Judging the statistical significance of GLS regression estimates is more difficult than in the OLS case. Split sample testing was used as a measure of the value of regression equations obtained using GLS (see section 7). Section 11.6 describes the different statistical measures used to assess the significance of OLS regression equations and the expected prediction error using GLS regression.

Finally, ad-hoc software was used to develop the GLS regression equations. Standard commercial software is not available for applying these techniques. However, the various routines developed to estimate the GLS and OLS parameters utilize the same algorithms to invert matrices needed to compute the coefficients. Section 11.7 describes the comparisons made with commercial software to test the ad-hoc software used to develop the regression equations.

11.2. Linear least squares regression models

A general regression relationship can be written in the form:

$$y = b_0 + b_1 x_1 + b_2 x_2 + ...e \tag{11.1}$$

where y is the dependent variable, x_i are the independent variables, b_i are the regression equation parameters, and e is the regression residual error. The residual represents the inability of the independent variable to perfectly explain the variance of the dependent variable.

In this study, the equation usually involved a log transform of the data where the dependent variable is the log of a quantile, such as the 1% chance exceedance annual peak flow, and, the independent parameters are log values of hydro-meteorologic characteristics such as drainage area.

The regression coefficients are typically estimated using ordinary least squares analysis from observed data, where:

$$y_j = b_0 + b_1 x_{1,j} + b_2 x_{2,j} + ... e_j \tag{11.2}$$

where y_j is the jth observation of the dependent variable, the b_i are the i=0,1,2 ...p sample estimates of the coefficients of the $x_{i,j}$ independent variables, for each of the j observations (see Draper and Smith, 1966). For example in this study, the y_j would be the log estimates of the 1% chance exceedance flow at j=1, 2, 3 .... n, stream gages within the study region.

The coefficients of the regressions are estimated by minimizing the sum of squared residuals over all the observations. If the equation is written in matrix notation:

$$\mathbf{Y} = \mathbf{Xb} + \mathbf{e} \tag{11.3}$$

where now **Y** is a nx1 gage column vector of the dependent variables, **b** is a px1 column vector of the regression parameters, **X** is a nxp matrix of the observed independent variables, and e is a nx1 column vector of regression residual errors. For example, the matrices would have the following form for two independent variables:

$$\mathbf{Y} = \begin{matrix} y_1 \\ y_2 \\ y_3 \end{matrix}, \quad \mathbf{b} = \begin{matrix} b_0 \\ b_1 \\ b_2 \end{matrix}, \quad \mathbf{X} = \begin{matrix} 1 & x_{1,1} & x_{2,1} \\ 1 & x_{1,2} & x_{2,2} \\ 1 & x_{1,3} & x_{2,3} \end{matrix}, \quad \mathbf{e} = \begin{matrix} e_1 \\ e_2 \\ e_3 \end{matrix} \tag{11.4}$$

Minimizing the sum of squared residual errors, results in the following expression for the sample estimates of the regression parameters:

$$\mathbf{b} = (\mathbf{X'X})^{-1}(\mathbf{X'Y}) \tag{11.5}$$

where $\mathbf{X'}$ is the transpose of **X**, and $(\;)^{-1}$ is a matrix inverse, and $\mathbf{X'X}$ is a pxp matrix known as the “sum of squares” matrix (i.e., this matrix contains the sum of squares and all cross-sum of squares of the independent variables).

In obtaining the regression estimates, the goal is to obtain best estimates in the sense that the estimates of the parameters and regression predictions are unbiased (estimation error is on the average zero) and the estimation/prediction error has minimum variance. In the case of OLS this will be true if the residual error has the following properties:

- homoscedastic (errors have equal spread about the regression)

- uncorrelated (error for any regression estimate are not linearly associated with any other error)
- normally distributed

Unfortunately, the residual errors do not have this property when estimating flow quantiles from gage data. The errors will not be homoscedastic; and the quantile estimation uncertainty will vary inversely proportional to the square root of the record length at each gage. Furthermore, the residuals errors show inter-gage correlation as a some non-linear function of the distance between gages. Under these circumstance, minimum variance estimates of the regression parameters are obtained using a generalized least squares approach as (see Draper and Smith, 1966):

$$\mathbf{b} = (\mathbf{X}'\mathbf{V}^{-1}\mathbf{X})^{-1}(\mathbf{X}'\mathbf{V}^{-1}\mathbf{Y}) \qquad (11.6)$$

where **V** is a nxn covariance matrix of residual errors.

GLS applications to obtain regional regression for flood quantiles is a standard approach used by the U.S. Geological Survey (e.g., see Blakemore, et al., 1997). The additional challenge in applying this approach is in estimating **V**.

11.3. Estimating the GLS residual error covariance matrix

11.3.1. Methodology

Estimation of the residual error covariance matrix is performed using the method proposed by Stedinger and Tasker (1986). In this approach, the regression residual error in estimating a flood quantile (such a the 1% exceedance flow) is assumed to be separable into a regression model error and a time sampling error. The regression model error is the error which would result if the flow quantiles were estimated perfectly from the record at each gage. The time sampling error occurs because of the limited record lengths available to estimate the flow quantiles at each gage. The magnitude of this error is inversely proportional to the square root of the record length.

As an example of how this error model is constructed, consider how the covariance matrix is constructed in the two gage case where in equations (11.2)-(11.6), j=1,2:

$$\mathbf{V} = \begin{matrix} d^2 + v_{1,1}^2 & v_{1,2} \\ v_{2,1} & d^2 + v_{2,2}^2 \end{matrix} \qquad (11.7)$$

where d^2 is regression model error, $v_{i,j}^2$ are the time sampling error covariances. In the case i=k, then the covariance is the error variance for a particular gage and when i≠k, then the off-diagonal matrix error covariance result from the inter-gage correlation of maximum flow values. Note also that the matrix is symmetric with $v_{i,j}=v_{j,i}$

If the maximum annual flows are not correlated with other gage flows, then the off-diagonal values become zero, and covariance error matrix becomes:

$$\mathbf{V} = \begin{matrix} d^2+v_{1,1}^2 & 0 \\ 0 & d^2+v_{2,2}^2 \end{matrix} \tag{11.8}$$

When these residual errors exhibit no inter-gage correlation, then the regression is referred to as weighted least squares (WLS). In the WLS solution for the parameters, $\mathbf{V^{-1}}$ becomes

$$V^{-1} = \begin{matrix} 1/_{d^2+v_{1,1}^2} & 0 \\ 0 & 1/_{d^2+v_{2,2}^2} \end{matrix} \tag{11.9}$$

and in equation (11.6) it can be seen that the estimate flow quantiles, $\mathbf{Y}$, are weighted inversely proportional to the estimation error when computing the regression parameters $\mathbf{b}$. Consequently, the longer the record length at a particular gage, the smaller $v_{i,i}$, and the larger weight given to a particular estimate of a flow quantile at a gage.

The Stedinger and Tasker error model reduces to OLS if the time sampling error is zero (i.e., if the population estimate of flow quantiles are known). In this case, the residual error matrix reduces to:

$$\mathbf{V} = \begin{matrix} d^2 & 0 \\ 0 & d^2 \end{matrix} = (\mathrm{se})^2 \begin{matrix} 1 & 0 \\ 0 & 1 \end{matrix} \tag{11.10}$$

where now the regression error $d^2=(se)^2$, se is the usual standard error of the regression, and equation (11.6) reduces to (11.5).

The errors in the Stedinger and Tasker model are estimated using the following relationships:

$$v_{i,i}^2 = s_i^2[1 + k_i g_i + 0.5k_i^2(1 + 0.75g_i^2)]/n_i \tag{11.11}$$

$$v_{i,j} = 0.5\rho_{i,j}s_i s_j \frac{2 + k_i g_i + k_i k_j(\rho_{i,j} + 0.75g_i g_j)}{\max(n_i, n_j)} \tag{11.12}$$

where, indices refer to gage i versus gage j s_i^2 is the sample variance of the log flows, k_i is log-Pearson III standard deviate for the sample skew g_i, and exceedance probability for the flow quantile involved in the regression, and n_i is the number of years of record at the gage, $\rho_{i,j}$ is the correlation between maximum flows for concurrent periods of records for gages i and j.

The regression model error term is determined by iteratively solving (see Johnston, 1972, p210) equation (11.6) and:

$$\mathbf{e}'\mathbf{V}^{-1}\mathbf{e} = \text{n-p} \tag{11.13}$$

where the residual errors are estimated from equation (11.3) after solving equation (11.6) for the regression parameters **b**. The iterative procedure is required because to solve for **b**, until d^2 is known. Consequently, 11.6 and 11.13 are two equations with two unknowns, **b** and d^2. The iterative solution proceeds by finding an OLS solution for **b**, assuming d^2 is the standard error of the OLS regression and substituting into equation (11.13). A secant iteration procedure is then followed to adjust estimates of d^2 and **b** to satisfy both equation (11.6) and (11.13).

11.3.2. Estimates

Table 11.1 provides estimates of the inter-gage correlation for Lake Tahoe gages for concurrent periods of record for use in (11.12). In certain circumstances, a sufficient concurrent period was not available to compute the correlation. In this circumstance, a nearest neighbor approach was used to estimate the correlation (i.e., the closest gage correlation was used).

The high inter-station correlation makes the covariance matrix **V** non-negative definite, preventing the computation of the inverse. Effectively, this means redundant information exists in the flow record. Tasker and Stedinger perform a regional smoothing relating dependence to inter-gage dependence to effectively reduce the redundancy in the information, and allowing the covariance to be inverted in the solution of the GLS equation. An alternative approach was taken where the off-diagonal elements were reduced in relationship to the matrix diagonal until the matrix could be inverted. This approach more generally capture the empirical dependence in the flow records, while at the same time reducing the redundancy in the flow information.

Table 11.1: Lake Tahoe Basin inter-gage correlation

USGS ID	(1)	(2)	USGS ID	(1)	(2)	USGS ID	(1)	(2)	USGS ID	(1)	(2)	USGS ID	(1)	(2)
[1]10336580			**10336600**			**103366092**			**10336610**			**10336626**		
10336600	11	0.95	103366092	11	0.97	10336610	10	0.9314	10336626	17	0.7365	10336635	5	0.399
103366092	11	0.9739	10336610	11	0.7721	10336626	18	0.85	10336635	11	0.83	10336645	12	0.9
10336610	10	0.9431	10336626	18	0.8469	10336635	11	0.83	10336645	20	0.9623	10336660	24	0.8878
10336626	18	0.84	10336635	11	0.8302	10336645	11	0.9802	10336660	25	0.9369	10336674	20	0.92
10336635	11	0.95	10336645	6	0.9431	10336660	11	0.9755	10336674	9	0.9295	10336675	20	0.92
10336645	11	0.9608	10336660	26	0.8835	10336674	10	0.9282	10336675	9	0.9509	10336676	20	0.9206
10336660	11	0.9728	10336674	14	0.95	10336675	10	0.9713	10336676	24	0.8982	10336693	10	0.343
10336674	10	0.9504	10336675	14	0.95	10336676	11	0.9637	10336693	4	0.6355	10336730	9	0.548
10336675	10	0.9817	10336676	14	0.958	10336693	12	0.4186	10336730	16	0.9536	10336740	9	0.693
10336676	11	0.9638	10336693	12	0.4186	10336730	11	0.8633	10336740	17	0.8487	10336756	10	0.62
10336693	12	0.4186	10336730	4	0.6271	10336740	11	0.7657	10336756	10	0.6795	103367585	11	0.6
10336730	11	0.8599	10336740	3	0.6485	10336756	10	0.5708	103367585	10	0.6387	103367592	11	0.76
10336740	11	0.751	10336756	10	0.65	103367585	11	0.6594	103367592	11	0.8357	10336770	10	0.64
10336756	10	0.6417	103367585	10	0.65	103367592	10	0.7279	10336770	10	0.7007	10336775	10	0.65
103367585	11	0.6701	103367592	10	0.65	10336770	10	0.6423	10336775	11	0.9507	10336780	24	0.7503
103367592	10	0.8131	10336770	10	0.65	10336775	11	0.9291	10336780	25	0.9057			
10336770	10	0.556	10336775	10	0.65	10336780	10	0.9161						
10336775	11	0.8971	10336780	26	0.8904									
10336780	10	0.8892												

(1) Concurrent period with [1]bold-faced gage or concurrent period based on nearest gage
(2) Correlation annual peaks or correlation using a nearest neighbor gage with bold-faced [1]gage
[1]Bold-faced USGS ID correlation with other gages in column

Table 11.1: Lake Tahoe Basin inter-gage correlation (continued)

USGS ID	(1)	(2)	USGS ID	(1)	(2)	USGS ID	(1)	(2)	USGS ID	(1)	(2)	USGS ID	(1)	(2)
10336635			**10336645**			**10336660**			**10336674**			**10336675**		
10336645	11	0.9802	10336660	22	0.9701	10336674	11	0.9197	10336675	10	0.9641	10336676	10	0.9952
10336660	11	0.7594	10336674	11	0.9039	10336675	10	0.9767	10336676	11	0.9617	10336693	6	0.7312
10336674	10	0.92	10336675	10	0.9569	10336676	30	0.9772	10336693	6	0.7312	10336730	10	0.8685
10336675	10	0.97	10336676	22	0.9689	10336693	12	0.3294	10336730	10	0.7521	10336740	10	0.8031
10336676	11	0.96	10336693	7	0.9587	10336730	18	0.8923	10336740	10	0.8361	10336756	9	0.5788
10336693	7	0.9587	10336730	14	0.9249	10336740	18	0.7633	10336756	9	0.6515	103367585	10	0.9025
10336730	11	0.86	10336740	18	0.7831	10336756	10	0.6282	103367585	10	0.8152	103367592	9	0.881
10336740	11	0.77	10336756	10	0.6139	103367585	11	0.5995	103367592	9	0.8984	10336770	9	0.5493
10336756	10	0.57	103367585	11	0.7038	103367592	11	0.7603	10336770	9	0.4723	10336775	10	0.8633
103367585	11	0.66	103367592	11	0.8108	10336770	10	0.6362	10336775	10	0.7873	10336780	9	0.8746
103367592	10	0.73	10336770	10	0.7249	10336775	12	0.9339	10336780	9	0.8546			
10336770	11	0.8	10336775	12	0.9637	10336780	40	0.9126						
10336775	11	0.8	10336780	20	0.9369									
10336780	11	0.8035												

(1) Concurrent period with [1]bold faced gage or concurrent period based on nearest gage
(2) Correlation annual peaks or correlation using a nearest neighbor gage with bold faced [1]gage
[1]Bold faced USGS ID correlation with other gages in column

Table 11.1: Lake Tahoe Basin inter-gage correlation (continued)

USGS ID	(1)	(2)	USGS ID	(1)	(2)	USGS ID	(1)	(2)	USGS ID	(1)	(2)	USGS ID	(1)	(2)
10336676			**10336693**			**10336730**	**18**		**10336740**			**10336756**		
10336693	6	0.7312	10336730	4	0.5248	10336740	14	0.802	10336756	10	0.8027	103367585	10	0.1011
10336730	17	0.8741	10336740	11	0.77	10336756	10	0.6316	103367585	11	0.3976	103367592	10	0.5783
10336740	18	0.8229	10336756	10	0.57	103367585	11	0.6889	103367592	11	0.682	10336770	10	0.3286
10336756	10	0.6522	103367585	11	0.66	103367592	11	0.7839	10336770	10	0.7237	10336775	10	0.6014
103367585	11	0.5531	103367592	10	0.73	10336770	10	0.7576	10336775	12	0.7917	10336780	10	0.5981
103367592	11	0.748	10336770	11	0.8	10336775	12	0.9198	10336780	17	0.8			
10336770	10	0.6587	10336775	11	0.8	10336780	17	0.9242						
10336775	12	0.903	10336780	12	0.5914									
10336780	28	0.9132												

(1) Concurrent period with [1]bold faced gage or concurrent period based on nearest gage
(2) Correlation annual peaks or correlation using a nearest neighbor gage with bold faced [1]gage
[1]Bold faced USGS ID correlation with other gages in column

Table 11.1: Lake Tahoe Basin inter-gage correlation (continued)

USGS ID	(1)	(2)	USGS ID	(1)	(2)	USGS ID	(1)	(2)	USGS ID	(1)	(2)
103367585			**103367592**			**10336770**			**10336775**		
103367592	10	0.8398	10336770	10	0.3261	10336775	10	0.8322	10336780	11	0.9865
10336770	10	0.4206	10336775	11	0.748	10336780	10	0.8437			
10336775	11	0.6603	10336780	11	0.7737						
10336780	10	0.6456									

(1) Concurrent period with [1]bold-faced gage or concurrent period based on nearest gage
(2) Correlation annual peaks or correlation using a nearest neighbor gage with bold-faced [1]gage
[1]Bold-faced USGS ID correlation with other gages in column

11.4. Effective record length computation

The peak flow duration frequency curves were computed by using historic information to judge the 1997 event to be the largest flow to occur in the past 103 years at many of the gages within the study area. Although this application assigns a plotting position of about 1/103 to the event, this does not mean that the period of record is actually 103 years. Rather, the **effective** record length has to be something less, somewhere between the gage systematic record (the record systematically recorded by the USGS) and this historic period.

The effective record length was computed by Monte Carlos simulation using the following algorithm:

1) Simulate n= 103 annual peak flows given the mean, standard deviation and skew of the log-flows at a particular gage;
2) Compute the log-Pearson III distribution from the n flow values;
3) Select the first n_s = systematic record length flows minus one, plus the largest event in the n simulated values created in step 1); compute a log-Pearson III distribution for this set of data by assigning the historic weighting corresponding to n_h=n to the largest event
4) Repeat steps 1-4 to obtain a large sample of frequency curves for the full period and historically weighted data;
5) Compute the mean square error (mse) for quantiles for interest in the study;
6) Repeat steps 1-5 until the estimates of mse stabilize (i.e., increase the sample of frequency curves until the numerical error in the estimated mse is relatively small).

The mse is simply calculated as the sum of squared differences between the mean quantile simulated and the quantile estimated for each simulation obtained in 1) or 2). The mean quantile is just the average quantile for all frequency curves computed in steps 2) and 3).

The effective record length can be computed as follows, recognizing that mse is inversely proportional to the record length:

$$n_e = \frac{mse_{n_h}}{mse_n} \qquad (11.14)$$

where mse_n is the mean square error for a particular quantile (e.g., the 1% annual peak flow) for the full period of record, mse_{n_h} is the mean square error for the quantile estimate using the historic weighting. Less flow data is available for the historically weighted curves causing these curves to have greater mse than the frequency curves computed with the full period of record. Consequently, the effective record length will always be less than the full historic period of record (n=103 years) because the mse is greater for the historically weighted curve. Table 11.2 displays the effective record lengths computed for the Lake Tahoe basin gages for the quantiles of interest. Note that for some of the smaller exceedance probabilities, the effective record length was computed to be slightly smaller than the systematic period. This reflects some minor numerical error in computing the mse using the simulation methodology.

Table 11.2: Effective record length for historic weighting given to the 1997 event

USGS ID	Watershed	[1]years	[2]0.99	0.95	0.9	0.8	0.5	0.2	0.1	0.04	0.02	0.01	0.002
10336580	Upper Truckee River	11	16	11	[3]9	10	11	11	16	24	30	35	42
10336600	Upper Truckee River	26	-1										
103366092	Upper Truckee River	11	12	10	10	10	11	11	13	18	21	23	27
10336610	Upper Truckee	25	-1										
10336626	Taylor Creek	24	-1										
10336645	General Creek	22	24	22	22	21	21	23	27	33	36	38	40
10336660	Blackwood Creek	42	46	43	42	42	42	45	53	62	66	69	71
10336674	Ward Creek	11	14	12	11	11	11	10	12	17	20	23	24
10336675	Ward Creek	11	12	11	10	10	11	11	13	17	20	22	25
10336676	Ward Creek	30	32	30	30	30	29	32	37	44	48	50	52
10336693	Wood Creek	12	-1										
10336730	Glenbrook Creek	18	19	18	17	17	17	19	23	29	33	35	38
10336740	Logan House Creek	18	21	19	18	18	18	18	20	26	30	32	33
10336756	Edgewood Creek	11	15	12	11	11	12	10	12	20	24	26	24
10336635	Lake Tahoe Tributary	10	-1										
103367585	Edgewood Creek	11	-1										
103367592	Eagle Rock Creek	11	13	11	11	11	11	11	12	16	20	22	24
10336770	Trout Creek	10	-1										
10336775	Trout Creek	11	11	10	10	10	11	11	14	19	23	26	30
10336780	Trout Creek	40	42	40	40	40	40	43	48	55	58	59	60

[1]Systematic period of record

[2]Effective record length for exceedance probability, (-1) indicates no historic weighting of the 1997 event for this gage.

[3]Effective record lengths smaller than systematic period reflect numerical error in estimating mse using Monte Carlo simulation

11.5. Leverage measures of regression sensitivity to range in data values

11.5.1. Derivation and application

The sensitivity of the regression results to individual points is an important consideration particularly when there is a limited amount of data and a relatively large spread in the independent variable values. In this study, a particular concern is the large range in contributing gage drainage area, containing only a few relatively large magnitude drainage areas.

To answer this concern, A statistical measure termed "leverage" was computed to determine whether or not the residual error associated with any set of gage independent parameters has undue influence on regression parameter. A sensitivity analysis on regression results was performed when an independent set of parameters exhibited unusually large values of leverage.

Mathematically, leverage is defined for GLS as the rate of change of prediction to change in prediction error as (see Tasker and Stedinger, 1989):

$$\mathrm{H}^{*}_{\mathrm{ii}} = \frac{\partial(\mathbf{x_i b})}{\partial(\mathbf{e_i})} = diag\left[\mathbf{X(X'V^{-1}X)^{-1}X'V^{-1}}\right]_{\mathrm{ii}} \tag{11.15}$$

where ($\mathbf{x_i b}$) is an individual regression prediction, and $\mathbf{e_i}$ is the associate residual error, $diag[\ ]_i$ refers to the i^{th} diagonal element of the nxn matrix inside the brackets, n being the number of gages used in the regression. In the case of OLS, equation (11.15) reduces to:

$$\mathrm{H}^{\mathrm{O}}_{\mathrm{ii}} = diag[\mathbf{X(X'X)X^{-1})}]_{\mathrm{ii}} \tag{11.16}$$

On the average, the leverage of any set of independent observations will have value p/n (where p is the number of parameters). Individual sets with leverage values greater than 2p/n can be considered to have a high magnitude of leverage. Sensitivity analysis was indicated when these sets were identified in performing the regression analysis.

An application to the simple regression described by equation (11.4) reveals how leverage measures the relative contribution of each variable to the regression results. For example consider the leverage of two observations to leverage for the one independent variable case. The diagonal elements of H^{O} becomes:

$$\begin{aligned} \mathrm{H}^{\mathrm{O}}_{1,1} &= \frac{1}{\mathrm{n}}\frac{\sum(\mathrm{x_i}\text{-}\mathrm{x_1})^2}{\sum(\mathrm{x_i}\text{-}\bar{\mathrm{x}})^2} \\ \mathrm{H}^{\mathrm{O}}_{2,2} &= \frac{1}{\mathrm{n}}\frac{\sum(\mathrm{x_i}\text{-}\mathrm{x_2})^2}{\sum(\mathrm{x_i}\text{-}\bar{\mathrm{x}})^2} \end{aligned} \tag{11.17}$$

where x_1, x_2 are individual observations of the independent variable (e.g., drainage area for a gage) $\bar{x}$ is the average of the independent variable estimates, and n is total number of independent observations. As can be seen, leverage of an individual observation is the average of the ratio of the sum of square differences between all observations and the individual observation to the sum of squared deviations from the mean. Basically, leverage measures the ratio of the variation of all the independent observations from the observation of interest, to the variation from the mean of the independent observations.

The average leverage of any data point will equal **p/n** where n is the number of observations, and p is the number of regression constants (i.e., **b** in equation 11.3) including the intercept. Individual sets of observations (x_i) with leverages greater than **2p/n** should cause concern, and leverages greater than **3p/n** should be singled out for closer inspection.

In this study, if the leverage of an observation in any regression application (OLS or GLS) exceeded 2p/n, then regression results were tested with regard to the sensitivity of predictions to excluding this point from the data set.

11.5.2. Cook's Statistic

Cook's statistic provides a measure of the influence of an individual observation which is related to leverage. This statistic is computed for OLS as (see Tasker and Stedinger, 1989):

$$D_i = \frac{e_i^2 \mathbf{H_{ii}}}{p(1-\mathbf{H_{ii}})^2 s_e^2} \tag{11.18}$$

where H_{ii} is the leverage for an individual observation, e_i is the regression residual for that observations, p is the number of parameters for the regression, and s_e^2 is the standard error of the regression. For GLS, the statistic takes the form:

$$D_i = \frac{1}{p} \frac{\left[\mathbf{H^* V}\right]_{\mathbf{ii}} e_i^2}{[(\mathbf{I} - \mathbf{H^*})\mathbf{V}]_{\mathbf{ii}}^2} \tag{11.19}$$

where **[ ]$_{\mathbf{ii}}$** is the iith diagonal elements of the contained array, **I** is the identity matrix (i.e., a matrix whose diagonal elements are 1, and all other elements are zero, and the **V** and $\mathbf{H^*}$ matrices are defined in equations (11.7) and (11.15). Observations with values greater than 4/n, where n is the number of observations, were examined to see the sensitivity of regression predictions to these values.

11.6. Testing statistical significance of the regression

11.6.1. Ordinary least squares regression

The statistical significance of a particular OLS regression was determined to see if individual regression coefficients were significantly different from zero and if the error residuals were uncorrelated. These test were only applied to the applications to low-flow and flow-duration where only OLS was applied. The next section discusses significance tests for the GLS approach.

The significance of a regression coefficient estimated from equation (11.5) is examined by performing the hypothesis test $b_i = 0$ versus $b_i \neq 0$ using the statistic (see standard texts on regression analysis, e.g., Haan, 1977, chapter 10):

$$t=\frac{\beta_i - b_i}{s_{b_i}} \tag{11.20}$$

where t has a Student's t distribution, $\beta_i = 0$, s_{b_i} is the sample variance of b_i. The hypothesis that $b_i=0$ is rejected if $|t| > t_{1-\alpha/2,n-p}$, where α is the significance level (e.g., 0.10 probability), n is the number of observations and p is the number of b_i regression parameters.

The statistical significance test depends on the assumptions that the residuals are uncorrelated and normally distributed. The distribution and significance of the correlation was examined using STATGRAPHICS (1999), a commercial statistical software package. The distribution of the residuals seemed reasonably normal based on plots of the data on normal probability scale. Residual correlation was not found to be statistically significant for the regressions investigated based on the Durbin-Watson statistic (see, Johnston, 1972).

11.6.2. Regressions standard error and average prediction error

General tests for the statistical significance of GLS regression coefficients do not exist because of the distributional characteristics of the residual errors in these applications. Instead, Tasker and Stedinger (1989) recommend the computation of an average prediction error to evaluate the accuracy of regression predictions. The average prediction error for a regression equation is the average of the square root of the mean square error of the individual mean square error of prediction for all gages used in developing the regression. The regression means square prediction error for a particular gage is computed as:

$$mse_x = \mathbf{x}'\left(\mathbf{X}'\mathbf{V}^{-1}\mathbf{X}\right)^{-1}\mathbf{x} \tag{11.21}$$

where **x** is a vector of independent variables. For example, if drainage area, mean basin elevation and mean annual precipitation were the independent variables in the regression then x would have the form:

$$x = \begin{matrix} 1 \\ A \\ Elev \\ MAP \end{matrix} \qquad (11.22)$$

where A = area, Elev = mean basin elevation, MAP = mean annual precipitation.

This measure is substituted for the standard error typically used for OLS regression. The standard error is computed as the square root of average of the sum of squared differences between regression predictions and the observed dependent variables (the flow quantiles in this study). This measure of prediction error is useful for OLS application because the assumption is that the prediction error is independent and equal for all combination of the regression independent variables (i.e., the errors are homoscedastic). This assumption is not true for the residual in a GLS regression, and more importantly, is generally untrue for flow quantiles because of differing gage flow record lengths and correlation between gage flows. Consequently, the average prediction error is used as a measure which accounts for the variation in regression prediction depending on the gage record lengths and inter-gage flow correlation.

11.7. Software comparisons

11.7.1. Comparisons for OLS regression

The ad-hoc software used to develop regression equations for the peak and annual maximum flow frequency analysis was tested by comparison with results from STATGRAPHICS (1999) commercial software. The ad-hoc and commercial software agrees almost perfectly as is shown in Table 11.5 for the regressions developed for peak annual stream flow from the data displayed in Tables 11.3-11.4.

11.7.2. Comparisons for WLS regression

Solving for the regression parameters for WLS and GLS regressions involves the solution to the same basic equations (see equation (11.6)). The ad-hoc software used in this study to apply the WLS regression was tested in comparisons with results obtained from STATGRAPHICS. The STATGRAPHICS commercial software can be used to compute WLS coefficients given weights for the diagonal elements of the covariance matrix of observations see equation (11.9). Table 11.6 displays the peak annual maximum Lake Tahoe regression data and covariance weights used in the comparisons. Table 11.7 shows that the regression coefficients obtained with each software application agree very well.

Table 11.3: Test log quantile data for OLS regression software (Preliminary estimates of quantiles for Lake Tahoe)

USGS ID	99	95	90	80	50	20	10	4	2	1	0.2
10336580	2.1073	2.2121	2.2801	2.3751	2.5980	2.8800	3.0525	3.2565	3.3994	3.5357	3.8342
10336600	2.1680	2.3639	2.4690	2.5968	2.8430	3.0916	3.2224	3.3627	3.4537	3.5358	3.7027
103366092	2.1328	2.3395	2.4581	2.6099	2.9258	3.2763	3.4739	3.6956	3.8450	3.9835	4.2763
10336610	2.1176	2.3194	2.4333	2.5772	2.8711	3.1903	3.3674	3.5642	3.6958	3.8171	4.0715
10336626	1.8525	1.9947	2.0811	2.1962	2.4502	2.7510	2.9279	3.1320	3.2724	3.4046	3.6896
10336635	0.2068	0.3711	0.4698	0.5999	0.8808	1.2068	1.3962	1.6128	1.7604	1.8998	2.1973
10336645	1.5452	1.7729	1.8944	2.0416	2.3235	2.6056	2.7533	2.9109	3.0127	3.1044	3.2900
10336660	1.8303	2.0242	2.1374	2.2840	2.5943	2.9456	3.1463	3.3734	3.5275	3.6711	3.9766
10336674	1.5528	1.7717	1.8922	2.0417	2.3389	2.6507	2.8197	3.0046	3.1265	3.2379	3.4685
10336675	1.6911	1.9024	2.0250	2.1830	2.5157	2.8897	3.1023	3.3423	3.5047	3.6558	3.9764
10336676	1.5267	1.7855	1.9286	2.1068	2.4627	2.8385	3.0432	3.2677	3.4161	3.5520	3.8339
10336693	0.2330	0.5922	0.7612	0.9474	1.2450	1.4730	1.5669	1.6499	1.6949	1.7300	1.7872
10336730	-0.0969	0.1761	0.3345	0.5366	0.9590	1.4281	1.6937	1.9921	2.1937	2.3808	2.7765
10336740	-0.5850	-0.2007	-0.0088	0.2068	0.5798	0.8976	1.0414	1.1818	1.2648	1.3345	1.4609
10336756	-1.6990	-1.0000	-0.6198	-0.2291	0.3802	0.7853	0.9395	1.0607	1.1206	1.1644	1.2253
103367585	-0.0757	0.2577	0.4314	0.6425	1.0453	1.4409	1.6474	1.8663	2.0073	2.1335	2.3881
103367592	-0.3872	-0.2147	-0.1192	-0.0132	0.2041	0.3802	0.4771	0.5911	0.6532	0.7076	0.8261
10336770	1.0577	1.3497	1.4883	1.6407	1.8871	2.0788	2.1593	2.2310	2.2704	2.3015	2.3533
10336775	1.1092	1.3479	1.4820	1.6506	1.9930	2.3625	2.5663	2.7923	2.9429	3.0815	3.3713
10336780	1.3817	1.6103	1.7322	1.8794	2.1608	2.4419	2.5885	2.7448	2.8457	2.9363	3.1197

Table 11.4: Log-parameters used for testing OLS regression software

USGS ID	area (sq mi)	elevation (ft)	MAP (inches)
10336580	1.148911	3.916906	1.715082
10336600	1.519828	3.905383	1.702376
103366092	1.535041	3.902887	1.714422
10336610	1.739572	3.881626	1.672171
10336626	1.222716	3.880735	1.707101
10336635	-0.19382	3.851656	1.649013
10336645	0.871573	3.857134	1.685071
10336660	1.049218	3.861097	1.739117
10336674	0.695482	3.876896	1.829684
10336675	0.952792	3.865783	1.792998
10336676	0.986772	3.862663	1.778721
10336693	0.227887	3.913753	1.61883
10336730	0.613842	3.866242	1.42447
10336740	0.320146	3.893027	1.472538
10336756	-0.09151	3.881688	1.451291
103367585	0.495544	3.876757	1.462634
103367592	-0.20066	3.918359	1.492243
10336770	0.869232	3.934835	1.627785
10336775	1.374748	3.893237	1.610107
10336780	1.564666	3.89936	1.588603

Table 11.5: Comparison of OLS regression results obtained from ad-hoc study software and STATGRAPHICS for Lake Tahoe Basin peak annual quantiles

	Ad-hoc software				STATGRAPHICS			
[1]p	constant	[2]area	[3]MAP	[4]elevation	constant	area	MAP	elevation
0.005	42.913	1.212	3.200	-11.881	42.913	1.212	3.200	-11.881
0.01	32.519	1.141	3.213	-9.254	32.519	1.140	3.213	-9.254
0.02	27.634	1.108	3.233	-8.027	27.634	1.108	3.233	-8.027
0.04	22.494	1.075	3.268	-6.743	22.494	1.074	3.268	-6.743
0.1	15.314	1.032	3.346	-4.966	15.314	1.032	3.346	-4.966
0.2	9.051	0.999	3.449	-3.435	9.051	0.999	3.449	-3.434
0.5	-5.118	0.948	3.782		-5.118	0.948	3.782	
0.8	-5.974	0.965	4.101		-5.974	0.965	4.101	
0.9	-6.524	0.984	4.325		-6.523	0.984	4.325	
0.95	-7.056	1.009	4.554		-7.056	1.009	4.554	
0.99	-8.099	1.059	5.009		-8.099	1.059	5.009	

[1]regression for $\log_{10}(Q_p)$ = constant + constant + $b_1\log_{10}$(area) + $b_2\log_{10}$(MAP) + $b_3\log_{10}$(elevation), where Q_p is the peak flow quantile for exceedance probability p
[2]b_1 regression coefficient for drainage area (sq mi)
[3]b_2 regression coefficient for basin average mean annual precipitation (inches)
[4]b_1 regression coefficient for basin average elevation (ft)

Table 11.6: Data used for comparison of ad-hoc study software and STATGRAPHICS

[1]USGS ID	[2]95%	50%	1%	[3]area	elevation	MAP	1% wt	1% cov	50% wt	50% cov	95% wt	95% wt
10336580	2.212054	2.598024	3.535661	1.148911	3.916906	1.715082	23.4	0.043	55.6	0.018	44.1	0.023
10336600	2.363931	2.843046	3.535775	1.519828	3.905383	1.702376	34.4	0.029	74.6	0.013	52.9	0.019
103366092	2.339491	2.925776	3.983509	1.535041	3.902887	1.714422	18.1	0.055	41.3	0.024	25.8	0.039
10336610	2.319439	2.871106	3.817122	1.739572	3.881626	1.672171	22.7	0.044	64.9	0.015	47.2	0.021
10336626	1.994669	2.450249	3.404594	1.222716	3.880735	1.707101	19.6	0.051	69.0	0.015	54.6	0.018
10336635	0.371068	0.880814	1.899821	-0.19382	3.851656	1.649013	17.9	0.056	46.1	0.022	31.3	0.032
10336645	1.772908	2.323458	3.104385	0.871573	3.857134	1.685071	32.1	0.031	49.3	0.020	26.5	0.038
10336660	2.024198	2.594282	3.671145	1.049218	3.861097	1.739117	17.1	0.058	41.7	0.024	30.4	0.033
10336674	1.771734	2.338855	3.237946	0.695482	3.876896	1.829684	23.1	0.043	45.5	0.022	28.2	0.036
10336675	1.902384	2.515741	3.655782	0.952792	3.865783	1.792998	16.4	0.061	38.5	0.026	24.2	0.041
10336676	1.785472	2.462697	3.552011	0.986772	3.862663	1.778721	22.0	0.046	61.0	0.016	41.8	0.024
10336693	0.592177	1.245019	1.729974	0.227887	3.913753	1.61883	42.0	0.024	54.1	0.019	14.3	0.070
10336730	0.176091	0.959041	2.380754	0.613842	3.866242	1.42447	11.0	0.091	28.2	0.035	18.0	0.056
10336740	-0.20066	0.579784	1.334454	0.320146	3.893027	1.472538	32.5	0.031	42.0	0.024	14.6	0.068
10336756	-1	0.380211	1.164353	-0.09151	3.881688	1.451291	13.3	0.075	23.1	0.043	3.2	0.314
103367585	0.257679	1.045323	2.133539	0.495544	3.876757	1.462634	11.2	0.090	32.7	0.031	16.4	0.061
103367592	-0.21467	0.20412	0.70757	-0.20066	3.918359	1.492243	41.0	0.024	66.2	0.015	40.2	0.025
10336770	1.349666	1.887054	2.301464	0.869232	3.934835	1.627785	34.5	0.029	60.2	0.017	20.1	0.050
10336775	1.347915	1.992995	3.081455	1.374748	3.893237	1.610107	19.6	0.051	38.0	0.026	22.2	0.045
10336780	1.610341	2.160769	2.936313	1.564666	3.89936	1.588603	29.2	0.034	49.3	0.020	26.5	0.038

[1]USGS ID is the U.S. Geological Service gage ID
[2]$\log_{10}$ quantiles for the 95%, 50% and 1% exceedance frequency annual peak discharge estimate for each gage
[3]$\log_{10}$Independent parameters, area = drainage area (sq mi), elevation = basin average elevation (ft), MAP = basin average mean annual precipitation, 1%, 50% and 95% wt = the WLS regression weights for each exceedance quantile (see equation (11.9)), 1%, 50% and 95% cov = the variance estimates used to compute the weights (see equation (11.8))

Table 11.7: Comparison of WLS regression results obtained from ad-hoc study software and STATGRAPHICS for Lake Tahoe Basin peak annual quantiles

	Ad-hoc software				STATGRAPHICS			
[1]p	constant	[2]area	[3]elevation	[4]MAP	constant	area	elevation	MAP
1%	27.8898	1.1073	-8.2799	3.7176	27.8956	1.1074	-8.2813	3.7172
50%	-3.3452	0.9659	-0.4855	3.8393	-3.3387	0.9660	-0.4872	3.8393
95%	-16.4283	0.9518	2.4979	4.4047	-16.4351	0.9518	2.4996	4.4050

[1]regression for $\log_{10}(Q_p)$ = constant + constant + $b_1\log_{10}$(area) + $b_2\log_{10}$(MAP) + $b_3\log_{10}$(elevation), where Q_p is the peak flow quantile for exceedance probability p
[2]b_1 regression coefficient for drainage area (sq mi)
[3]b_2 regression coefficient for basin average mean annual precipitation (inches)
[4]b_1 regression coefficient for basin average elevation (ft)

12. Appendix: summary statistics for gage frequency curves

The tables in this appendix provide the data not previously listed for regression analyses described in the previous sections. The following tables are included:

- Tables 12.1 - 12.6: log-statistics and first half log-Pearson III quantiles for first half of data, independent variables used to develop regression equations (see section 7).
- Tables 12.7 – 12.17: Lake Tahoe Peak annual flow log-statistics, seasonal distribution log-statistics for annual maximum volume-duration-frequency curves and annual maximum-volume-duration frequency curves

Table 12.1: Regional gages and statistics for split sample testing

(1)		USGS ID	first set of data			second set of data		
1	CONVICT CREEK	10265200	2.0107	0.2198	-0.45	1.9980	0.1849	-0.07
1	ROCK CREEK	10265700	2.0484	0.2202	-0.26	2.0340	0.2173	0.03
1	PINE CREEK	10267000	2.3401	0.1939	-0.84	2.3710	0.1720	-0.36
0	SILVER CREEK	10268700	0.3727	0.2314	0.24	0.4010	0.2600	0.35
1	BIG PINE CREEK	10276000	2.2623	0.1735	-0.09	2.2430	0.1820	0.09
0	COTTONWOOD CREEK	10286000	2.0051	0.4217	-1.34	2.0730	0.2852	-0.43
0	VIRGINIA CREEK	10289000	2.0347	0.4685	0.81	2.0890	0.4583	0.35
1	BUCKEYE CREEK	10291500	2.6149	0.2381	1.20	2.6570	0.2146	-0.09
1	SWAUGER CREEK	10292000	1.9442	0.4451	0.28	2.0170	0.4109	0.14
0	E WALKER RIVER	10293000	2.6708	0.2699	0.24	2.6580	0.2738	0.13
0	W WALKER RIVER	10295200	3.0801	0.1438	0.51	3.1080	0.1677	0.25
0	L WALKER RIVER	10295500	2.5596	0.2885	0.68	2.4960	0.2480	0.82
0	W WALKER RIVER	10296000	3.2722	0.2471	0.52	3.2830	0.2340	0.17
0	W WALKER RIVER	10296500	3.2564	0.2297	0.48	3.2760	0.2100	0.05
1	DESERT CREEK	10299100	1.7997	0.3379	0.20	1.6910	0.3214	0.12
1	REESE RIVER	10302010	1.5742	0.8035	-0.34	1.2090	0.7443	-0.81
1	SILVER CREEK	10304500	2.6530	0.2747	1.13	2.5830	0.2293	1.37
0	BRYANT CREEK	10308800	2.0115	0.5925	0.23	1.8620	0.4909	0.48
0	E FORK CARSON RIVER	10309000	3.4162	0.3152	0.61	3.4370	0.3160	0.51
1	W FORK CARSON RIVER	10310000	2.9218	0.3115	0.61	2.9320	0.2919	0.87
0	DAGGETT CREEK	10310400	1.1314	0.2913	0.31	1.1350	0.2975	0.39
1	CLEAR CREEK	10310500	1.4635	0.4271	0.13	1.4690	0.3922	0.24
0	CARSON RIVER	10311000	3.4096	0.4189	0.55	3.3620	0.4083	0.58
0	ASH CANYON	10311200	1.2286	0.4565	0.88	1.2480	0.4509	-0.44
1	BRUNSWICK CANYON	10311450	0.9783	1.0266	-0.67	1.0650	1.0880	-1.76
1	UPPER TRUCKEE	10336600	2.8447	0.2940	0.03	2.8390	0.2399	0.09
1	UPPER TRUCKEE	10336610	2.8889	0.3656	0.29	2.8380	0.2113	0.92
1	TAYLOR CREEK	10336626	2.4832	0.3348	0.60	2.5910	0.4033	0.31
0	GENERAL CREEK	10336645	2.3237	0.3351	0.00	2.3120	0.4035	-0.16
0	BLACKWOOD CREEK	10336660	2.6232	0.3965	0.44	2.5960	0.3882	0.39
0	WARD CREEK	10336676	2.4768	0.4355	0.20	2.5100	0.4796	-0.07
0	LITTLE TRUCKEE RIVER	10342000	3.0199	0.4260	0.97	0.9860	0.3979	0.22
1	SAGEHEN CREEK	10343500	2.0193	0.4766	0.05	0.6450	0.1957	0.46
0	GALENA CREEK	10348900	1.9173	0.5681	1.59	2.0940	0.3249	0.16
0	LONG VALLEY CREEK	10350100	1.9088	1.4019	-0.57	2.9360	0.3410	1.42
1	GLENBROOK CREEK	10336730	0.9922	0.5332	0.38	2.0200	0.4616	0.01
0	LOGAN HOUSE CREEK	10336740	0.5399	0.4153	-0.56	1.7600	0.3806	-0.08
0	TROUT CREEK	10336780	2.1605	0.3341	-0.01	2.0050	1.4976	-0.98

(1) gages selected for testing based on leverage

Table 12.2: Regional gages independent variables for split sample testing

Watershed	USGS ID	[1]Area	Elevation	MAP	Snowfall	Temperature
CONVICT CREEK	10265200	18.2	10251.09	37.44	321.06	36.14
ROCK CREEK	10265700	35.8	10691.34	28.62	311.30	34.34
PINE CREEK	10267000	36.4	10421.45	29.13	355.75	33.62
SILVER CREEK	10268700	19.7	8794.03	12.76	53.86	40.1
BIG PINE CREEK	10276000	39	9818.75	23.19	278.58	36.68
COTTONWOOD CREEK	10286000	40.1	10034.84	16.57	129.57	39.74
VIRGINIA CREEK	10289000	63.6	8354.52	19.92	120.75	41.54
BUCKEYE CREEK	10291500	44.1	9192.10	37.99	228.82	39.02
SWAUGER CREEK	10292000	52.8	8382.23	26.10	136.54	40.28
E WALKER RIVER	10293000	359	8247.39	24.06	144.33	40.64
W WALKER RIVER	10295200	73.4	9236.06	46.30	227.56	38.66
L WALKER RIVER	10295500	63.1	8682.39	34.37	167.76	39.56
W WALKER RIVER	10296000	181	8846.97	39.72	194.37	39.2
W WALKER RIVER	10296500	250	8610.00	36.02	173.43	39.56
DESERT CREEK	10299100	50.4	8365.07	26.81	131.61	40.46
REESE RIVER	10302010	14	6173.05	15.67	62.36	48.92
SILVER CREEK	10304500	19.6	8354.98	55.43	394.09	39.56
BRYANT CREEK	10308800	31	7348.91	33.94	165.83	43.52
E FORK CARSON RIVER	10309000	356	7636.34	38.94	229.06	41.72
W FORK CARSON RIVER	10310000	65.4	8069.92	45.91	347.44	40.82
DAGGETT CREEK	10310400	3.82	7291.13	26.14	133.35	43.7
CLEAR CREEK	10310500	15.5	6825.22	22.99	114.33	44.96
CARSON RIVER	10311000	886	6759.39	28.15	154.92	44.42
ASH CANYON	10311200	5.2	7321.35	26.02	144.49	44.6
BRUNSWICK CANYON	10311450	12.7	5806.52	14.72	39.96	48.56
UPPER TRUCKEE	10336600	33.1	8042.35	50.39	375.31	41
UPPER TRUCKEE	10336610	54.9	7614.23	47.01	321.85	41.72
TAYLOR CREEK	10336626	16.7	7598.62	50.94	297.28	42.44
GENERAL CREEK	10336645	7.44	7196.71	48.43	251.34	42.26
BLACKWOOD CREEK	10336660	11.2	7262.68	54.84	286.50	42.44
WARD CREEK	10336675	8.97	7341.47	62.09	314.45	42.26
LITTLE TRUCKEE RIVER	10336730	4.11	7349.24	26.57	98.94	43.7
SAGEHEN CREEK	10336740	2.09	7816.76	29.69	107.83	43.7
GALENA CREEK	10336780	36.7	7931.58	38.78	225.55	41.36
LONG VALLEY CREEK	10342000	36.5	7261.07	55.28	289.33	41.18
GLENBROOK CREEK	10343500	10.5	7097.51	37.76	259.41	41.72
LOGAN HOUSE CREEK	10348900	8.5	8319.50	46.26	232.68	42.26
TROUT CREEK	10350100	82.6	5929.90	13.62	53.11	48.56

[1]Area=Drainage area (sq mi), Elevation = mean basin elevation (ft msl), MAP = basin average mean annual precipitation, Snowfall= basin average mean total annual snowfall (inches), Temperature = mean annual temperature (^{o}F)

Table 12.3: Quantiles first half split sample test

Gage	[1]ID	[2]0.99	0.95	0.9	0.8	0.5	0.2	0.1	0.04	0.02	0.01	0.002
CONVICT CREEK	10265200	36	49	58	70	100	143	171	208	235	262	327
ROCK CREEK	10265700	34	48	57	71	108	165	206	261	304	350	464
PINE CREEK	10267000	84	118	140	170	241	330	384	447	490	532	620
SILVER CREEK	10268700	0.73	1.00	1.20	1.51	2.43	4.11	5.52	7.68	9.59	11.77	18.15
BIG PINE CREEK	10276000	68	89	103	123	174	249	301	369	422	477	612
COTTONWOOD CREEK	10286000	21	37	50	69	124	208	265	337	390	442	559
VIRGINIA CREEK	10289000	14	24	33	50	115	291	490	879	1301	1871	4029
BUCKEYE CREEK	10291500	139	199	240	300	457	689	850	1060	1221	1384	1779
SWAUGER CREEK	10292000	13	23	31	47	102	229	355	570	779	1035	1858
E WALKER RIVER	10293000	111	165	204	266	449	769	1028	1408	1731	2089	3074
W WALKER RIVER	10295200	561	699	791	923	1262	1765	2123	2604	2983	3381	4390
L WALKER RIVER	10295500	117	142	161	192	290	489	672	980	1277	1643	2854
W WALKER RIVER	10296000	585	812	971	1214	1889	3002	3858	5075	6080	7171	10087
W WALKER RIVER	10296500	623	857	1017	1254	1879	2830	3514	4433	5156	5910	7806
DESERT CREEK	10299100	9	15	19	26	48	91	128	185	235	293	460
REESE RIVER	10302010	0.11	0.69	1.64	4.26	20.32	70.12	118.96	192.46	251.75	312.18	449.66
SILVER CREEK	10304500	188.77	205.27	220.05	246.44	340.77	556.85	775.67	1173.34	1586.6	2131.1	4153.64
BRYANT CREEK	10308800	7.9	13.4	18.4	27.7	66.5	181.9	324.5	627.2	982.5	1494.7	3661.2
E FORK CARSON RIVER	10309000	666	929	1132	1468	2573	4925	7174	11025	14787	19468	35078
W FORK CARSON RIVER	10310000	276	342	394	482	777	1438	2104	3307	4548	6167	12050
DAGGETT CREEK	10310400	3	5	6	8	13	24	34	49	64	82	136
CLEAR CREEK	10310500	4.23	7.11	9.49	13.64	28.38	62.15	95.62	153.84	211.04	282.17	517.1
CARSON RIVER	10311000	388	581	742	1027	2101	4884	8011	14161	20951	30283	66939
ASH CANYON	10311200	1.14	2.85	4.5	7.6	19.08	43.01	63.12	92.25	116.01	141.09	203.69
BRUNSWICK CANYON	10311450	0	0.08	0.43	2.28	23.22	86.83	127.17	161.91	177.36	186.82	196.66
UPPER TRUCKEE	10336600	199	283	342	433	685	1097	1410	1850	2209	2595	3609
UPPER TRUCKEE	10336610	310	358	395	455	640	1001	1323	1846	2337	2930	4825
TAYLOR CREEK	10336626	56	92	123	177	372	838	1317	2177	3049	4160	7989
GENERAL CREEK	10336645	21	43	61	95	210	451	663	990	1275	1596	2487
BLACKWOOD CREEK	10336660	64	101	131	184	372	819	1279	2113	2966	4064	7919
WARD CREEK	10336676	23	51	78	128	328	823	1321	2177	2997	3987	7065
LITTLE TRUCKEE RIVER	10342000	1.34	2.28	3.07	4.45	9.37	20.72	31.97	51.55	70.77	94.64	173.21
SAGEHEN CREEK	10343500	1.81	2.24	2.54	3.00	4.26	6.36	8.00	10.38	12.39	14.62	20.80
GALENA CREEK	10348900	24	38	48	66	122	231	328	479	615	773	1240
LONG VALLEY CREEK	10350100	310	347	382	450	721	1498	2464	4600	7264	11365	31360
GLENBROOK CREEK	10336730	8.9	18.3	26.8	42.7	104.4	255.7	409.1	675.8	935.3	1253.1	2268.3
LOGAN HOUSE CREEK	10336740	7.1	13.4	18.6	27.6	58.2	120.8	175.8	261.0	336.1	421.2	662.0
TROUT CREEK	10336780	0.00	0.16	1.00	7.35	175.71	1911.88	5024.12	11639.27	18217.23	25729.93	44631.80

[1]Note that all gages were not used for split sample test, gages selected based on leverage statistic

[2]Exceedance probability

Table 12.4: Independent parameters used in Lake Tahoe regression analyses

USGS ID	Description	Area	Elevation	MAP	Snowfall	MAT
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	14.1	8258.6	51.9	417.7	40.5
10336600	Upper Truckee River near Meyers, CA	33.1	8042.4	50.4	375.3	41.0
103366092	Upper Truckee River at Highway 50 above Meyers, CA	34.3	7996.3	51.8	370.2	41.2
10336610	Upper Truckee River at South Lake Tahoe, CA	54.9	7614.2	47.0	321.9	41.7
10336626	Taylor Creek near Camp Richardson, CA	16.7	7598.6	50.9	297.3	42.4
10336635	Lake Tahoe Tributary near Meeks Bay	0.6	7106.5	44.6	265.3	42.4
10336645	General Creek near Meeks Bay, CA	7.4	7196.7	48.4	251.3	42.3
10336660	Blackwood Creek near Tahoe City, CA	11.2	7262.7	54.8	286.5	42.4
10336674	Ward Creek below Confluence near Tahoe City, CA	5.0	7531.8	67.6	318.6	42.3
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	9.0	7341.5	62.1	314.4	42.3
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	9.7	7288.9	60.1	309.4	42.3
10336693	Wood Creek near Crystal Bay, NV	1.7	8198.9	41.6	198.7	41.4
10336730	Glenbrook Creek at Glenbrook, NV	4.1	7349.2	26.6	98.9	43.7
10336740	Logan House Creek nr Glenbrook, NV	2.1	7816.8	29.7	107.8	43.7
10336756	Edgewood Creek Tributary near Daggett Pass. NV	0.8	7615.3	28.3	134.6	43.3
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	3.1	7529.4	29.0	138.1	43.0
103367592	Eagle Rock Creek nr Stateline, NV	0.6	8286.3	31.1	139.8	42.1
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	7.4	8606.7	42.4	281.0	40.6
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	23.7	7820.5	40.7	239.8	41.4
10336780	Trout Creek near Tahoe Valley, CA	36.7	7931.6	38.8	225.6	41.4

Area=Drainage area (sq mi), Elevation = mean basin elevation (ft msl), MAP = basin average mean annual precipitation (inches), Snowfall= basin average mean total annual snowfall (inches), MAT = mean annual temperature (^{o}F)

Table 12.5: Area weighted average of depth-duration-frequency estimates (NOAA-14, 50%, 20%, 10%, exceedance probability, 2 and 24 hour duration)

USGS ID	Gage Description	(1)	(2)	(3)	(4)	(5)	(6)
10336580	Upper Truckee River at S Upper Truckee Rd near Meyers, CA	0.81	4.10	0.99	5.06	1.14	5.84
10336600	Upper Truckee River near Meyers, CA	0.79	3.91	0.97	4.83	1.12	5.57
103366092	Upper Truckee River at Highway 50 above Meyers, CA	0.79	3.95	0.96	4.87	1.11	5.62
10336610	Upper Truckee River at South Lake Tahoe, CA	0.76	3.70	0.93	4.56	1.07	5.25
10336626	Taylor Creek near Camp Richardson, CA	0.77	3.97	0.94	4.88	1.08	5.62
10336635	Lake Tahoe Tributary near Meeks Bay	0.77	3.42	0.94	4.20	1.09	4.84
10336645	General Creek near Meeks Bay, CA	0.81	3.81	0.98	4.69	1.14	5.40
10336660	Blackwood Creek near Tahoe City, CA	0.85	4.64	1.03	5.72	1.19	6.60
10336674	Ward Creek below Confluence near Tahoe City, CA	0.89	5.23	1.08	6.44	1.26	7.41
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	0.86	4.93	1.06	6.07	1.23	7.00
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	0.86	4.83	1.04	5.95	1.22	6.85
10336693	Wood Creek near Crystal Bay, NV	0.77	3.85	0.98	4.90	1.17	5.77
10336730	Glenbrook Creek at Glenbrook, NV	0.67	2.63	0.84	3.32	0.99	3.89
10336740	Logan House Creek nr Glenbrook, NV	0.68	2.69	0.85	3.41	1.00	4.01
10336756	Edgewood Creek Tributary near Daggett Pass. NV	0.67	2.74	0.83	3.42	0.97	3.97
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	0.67	2.76	0.83	3.42	0.97	3.96
103367592	Eagle Rock Creek nr Stateline, NV	0.67	2.77	0.83	3.41	0.98	3.94
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	0.74	3.23	0.91	3.99	1.07	4.60
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	0.72	3.12	0.89	3.85	1.03	4.44
10336780	Trout Creek near Tahoe Valley, CA	0.71	3.06	0.88	3.77	1.03	4.35

(1) 50% 2hr, (2) 50% 24hr, (3) 20% 2hr, (4) 20% 24hr, (5) 10% 2hr, (6) 10% 24hr

Table 12.6: Area weighted average of depth-duration-frequency estimates (NOAA-14, 4%, 2%, 1%, exceedance probability, 2 and 24 hour duration)

USGS ID	Gage Description	(1)	(2)	(3)	(4)	(5)	(6)
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	1.37	6.90	1.55	7.72	1.76	8.57
10336600	Upper Truckee River near Meyers, CA	1.34	6.58	1.52	7.37	1.73	8.18
103366092	Upper Truckee River at Highway 50 above Meyers, CA	1.33	6.63	1.52	7.43	1.72	8.24
10336610	Upper Truckee River at South Lake Tahoe, CA	1.29	6.20	1.47	6.94	1.67	7.70
10336626	Taylor Creek near Camp Richardson, CA	1.29	6.63	1.47	7.41	1.67	8.20
10336635	Lake Tahoe Tributary near Meeks Bay	1.31	5.70	1.50	6.37	1.73	7.05
10336645	General Creek near Meeks Bay, CA	1.37	6.37	1.57	7.11	1.80	7.88
10336660	Blackwood Creek near Tahoe City, CA	1.44	7.78	1.66	8.70	1.92	9.64
10336674	Ward Creek below Confluence near Tahoe City, CA	1.52	8.73	1.75	9.76	2.03	10.81
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	1.49	8.25	1.71	9.21	2.00	10.21
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	1.48	8.07	1.70	9.02	1.99	10.00
10336693	Wood Creek near Crystal Bay, NV	1.44	7.00	1.68	7.98	1.96	9.03
10336730	Glenbrook Creek at Glenbrook, NV	1.21	4.69	1.39	5.33	1.60	6.01
10336740	Logan House Creek nr Glenbrook, NV	1.22	4.83	1.40	5.50	1.61	6.21
10336756	Edgewood Creek Tributary near Daggett Pass. NV	1.18	4.72	1.34	5.32	1.53	5.94
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	1.18	4.70	1.34	5.27	1.53	5.88
103367592	Eagle Rock Creek nr Stateline, NV	1.18	4.65	1.35	5.21	1.55	5.78
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	1.28	5.41	1.47	6.05	1.67	6.72
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	1.25	5.23	1.42	5.85	1.63	6.50
10336780	Trout Creek near Tahoe Valley, CA	1.24	5.13	1.42	5.74	1.62	6.37

(1) 4% 2hr, (2) 4% 24hr, (3) 2% 2hr, (4) 2% 24hr, (5) 1% 2hr, (6) 1% 24hr

Table 12.7: Lake Tahoe Basin Stream Gages statistics of $\log_{10}$ annual peak flows, systematic record

USGS ID	Description	[1]area	[2]years	[3]mean	[4]std dev	[5]skew	[6]high	[7]low
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	14.09	11	2.640	0.309	0.81	1	0
10336600	Upper Truckee River near Meyers, CA	33.1	26	2.845	0.294	0.03	0	0
103366092	Upper Truckee River at Highway 50 above Meyers, CA	34.28	11	2.950	0.398	0.37	0	0
10336610	Upper Truckee River at South Lake Tahoe, CA	54.9	25	2.889	0.366	0.29	0	0
10336626	Taylor Creek near Camp Richardson, CA	16.7	24	2.483	0.335	0.60	0	0
10336635	Lake Tahoe Tributary near Meeks Bay	0.64	30	2.477	0.435	0.20	0	0
10336645	General Creek near Meeks Bay, CA	7.44	22	2.324	0.335	0.00	0	0
10336660	Blackwood Creek near Tahoe City, CA	11.2	42	2.623	0.396	0.44	0	0
10336674	Ward Creek below Confluence near Tahoe City, CA	4.96	11	2.349	0.362	0.17	0	0
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	8.97	10	2.545	0.423	0.42	0	0
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	9.7	30	2.477	0.435	0.20	0	0
10336693	Wood Creek near Crystal Bay, NV	1.69	12	1.196	0.324	-0.92	0	0
10336730	Glenbrook Creek at Glenbrook, NV	4.11	18	0.992	0.533	0.38	0	0
10336740	Logan House Creek nr Glenbrook, NV	2.09	18	0.540	0.415	-0.56	0	0
10336756	Edgewood Creek Tributary near Daggett Pass. NV	0.81	10	0.243	0.645	-1.23	0	0
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	3.13	11	1.041	0.474	-0.03	0	0
103367592	Eagle Rock Creek nr Stateline, NV	0.63	11	0.186	0.236	-0.14	0	0
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	7.4	10	1.849	0.269	-0.87	0	0
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	23.7	12	2.012	0.424	0.27	0	0
10336780	Trout Creek near Tahoe Valley, CA	36.7	40	2.161	0.334	-0.01	0	0

[1]Drainage area (square miles)
[2]Number of peaks analyzed
[3]mean of log peaks
[4]standard deviation of log peaks
[5]skew coefficient of log peaks
[6]number of peaks flagged as high outliers (**peaks not deleted from analysis**)
[7]number of low-outliers and zero magnitude floods censored, conditional probability adjustment applied

Table 12.8: Lake Tahoe Basin Stream Gages statistics of $\log_{10}$ annual peak flows, historic weighting of the 1997 event

USGS ID	Description	[1]area	[2]years	[3]years	[4]mean	[5]std dev	[6]skew
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	14.09	11	103	2.58	0.229	0.24
10336600	Upper Truckee River near Meyers, CA	33.1	26	0	2.845	0.294	0.03
103366092	Upper Truckee River at Highway 50 above Meyers, CA	34.28	11	103	2.883	0.32	0.02
10336610	Upper Truckee River at South Lake Tahoe, CA	54.9	25	103	2.862	0.3316	0.07
10336626	Taylor Creek near Camp Richardson, CA	16.7	24	0	2.483	0.335	0.6
10336635	Lake Tahoe Tributary near Meeks Bay	0.64	30	103	2.302	0.315	-0.02
10336645	General Creek near Meeks Bay, CA	7.44	22	103	2.611	0.383	0.41
10336660	Blackwood Creek near Tahoe City, CA	11.2	42	103	2.283	0.279	-0.64
10336674	Ward Creek below Confluence near Tahoe City, CA	4.96	11	103	2.462	0.32	-0.21
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	8.97	10	103	2.454	0.41	0.1
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	9.7	30	0	1.196	0.324	-0.92
10336693	Wood Creek near Crystal Bay, NV	1.69	12	103	0.936	0.463	0.11
10336730	Glenbrook Creek at Glenbrook, NV	4.11	18	103	0.484	0.385	-0.51
10336740	Logan House Creek nr Glenbrook, NV	2.09	18	103	0.186	0.616	-0.95
10336756	Edgewood Creek Tributary near Daggett Pass. NV	0.81	10	0	1.041	0.474	-0.03
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	3.13	11	0	0.913	0.365	0.53
103367592	Eagle Rock Creek nr Stateline, NV	0.63	11	103	0.148	0.196	-0.49
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	7.4	10	103	1.283	0.315	0.39
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	23.7	12	0	1.849	0.269	-0.87
10336780	Trout Creek near Tahoe Valley, CA	36.7	40	103	1.955	0.369	0.24

[1]Drainage area (square miles)
[2]Number of peaks analyzed
[3]Historic period of record
[4]mean of log peaks
[5]standard deviation of log peaks
[6]skew coefficient of log peaks

Table 12.9: Lake Tahoe Basin Stream Gages log-Pearson III estimated annual peak quantiles (50%, 20%, 10%, 4%, 2%, 1%, 0.2%), systematic record versus estimate with historic period 1997 event

USGS ID	Description	years	[3]50	20	10	4	2	1	0.2
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	[1]11	396.3	758.6	1128.6	1804.9	2508.4	3432.9	6826.8
		[2]103	372.6	588.0	755.4	995.8	1196.5	1416.2	2012.4
10336600	Upper Truckee River near Meyers, CA	26	696.7	1234.7	1668.9	2305.0	2842.2	3433.8	5043.7
103366092	Upper Truckee River at Highway 50 above Meyers, CA	25	842.9	1889.5	2977.7	4961.1	6997.8	9627.4	18891.1
			760.7	1415.7	1961.9	2782.0	3488.6	4278.2	6474.8
10336610	[1]Upper Truckee River at South Lake Tahoe, CA	24	743.2	1549.8	2330.3	3666.3	4963.6	6563.3	11789.1
			721.7	1380.3	1946.9	2820.3	3590.6	4467.9	6983.5
10336626	Taylor Creek near Camp Richardson, CA	11	282.0	563.7	847.1	1355.1	1872.4	2538.6	4893.0
10336635	Lake Tahoe Tributary near Meeks Bay	22	7.6	16.1	24.9	41.0	57.6	79.4	157.5
		103							
10336645	General Creek near Meeks Bay, CA	42	210.6	403.3	566.6	814.5	1029.7	1271.7	1950.0
		103	201.0	369.4	506.9	709.5	881.2	1070.4	1584.9
10336660	Blackwood Creek near Tahoe City, CA	11	392.9	882.3	1400.4	2362.7	3369.1	4689.7	9476.4
		103	384.4	838.0	1304.6	2149.5	3013.5	4126.2	8036.8
10336674	Ward Creek below Confluence near Tahoe City, CA	10	218.2	447.4	660.3	1010.6	1338.2	1729.6	2940.7
		103	205.7	333.1	413.4	507.1	571.0	629.8	750.2
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	30	327.9	775.8	1265.6	2199.2	3196.5	4526.7	9472.1
		103	296.9	541.2	730.4	994.9	1208.0	1432.9	2002.7
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	12	290.2	689.5	1104.6	1852.1	2607.0	3564.6	6821.3
		103	280.0	626.4	963.0	1533.8	2079.8	2742.3	4835.5
10336693	Wood Creek near Crystal Bay, NV	18	17.6	29.7	36.9	44.7	49.5	53.7	61.3
10336730	Glenbrook Creek at Glenbrook, NV	18	9.1	26.8	49.4	98.2	156.2	240.3	597.7
		103	8.5	21.0	34.2	58.0	81.9	112.1	213.6
10336740	Logan House Creek nr Glenbrook, NV	10	3.8	7.9	11.0	15.2	18.4	21.6	28.9
		103	3.3	6.5	8.9	12.2	14.6	17.1	22.7
10336756	Edgewood Creek Tributary near Daggett Pass. NV	10	2.4	6.1	8.7	11.5	13.2	14.6	16.8
			1.9	5.2	7.7	11.0	13.3	15.4	19.6
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	12	11.0	28.0	44.0	74.0	100.0	140.0	240.0
		103							
103367592	Eagle Rock Creek nr Stateline, NV	40	1.6	2.4	3.0	3.9	4.5	10.0	10.0
		103	1.5	2.1	2.4	2.9	3.2	3.4	4.0
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	11	77.1	119.9	144.3	170.2	186.4	200.2	225.6
		103							
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	11	98.4	230.4	368.4	619.8	876.7	1206.3	2351.3
			87.2	182.2	273.0	426.4	573.4	752.6	1326.8
10336780	Trout Creek near Tahoe Valley, CA	11	144.8	276.6	387.7	555.6	700.9	863.6	1317.4
		103	139.1	258.3	356.7	502.7	627.1	764.9	1142.5
	average difference (systematic vs. historic)		**0.08**	**0.17**	**0.22**	**0.28**	**0.32**	**0.37**	**0.41**

[1]Systematic period of record (gage record), [2]historic period assigned to 1997 event [3]Percent chance exceedance

Table 12.10: Lake Tahoe Basin Stream Gages log-Pearson III estimated annual peak quantiles (99%, 95%, 90%, 80%), systematic record vs. estimated with historic period 1997 event

USGS ID	Description	years	[1]99	95	90	80
10336580	Upper Truckee River at S Upper Truckee Rd Near Meyers, CA	11	128.0	163.0	190.6	237.2
		103	122.7	166.2	196.8	243.1
10336600	Upper Truckee River near Meyers, CA	26	147.2	231.2	294.4	395.2
103366092	Upper Truckee River at Highway 50 above Meyers, CA	25	135.8	218.5	287.2	407.3
			139.6	228.6	297.7	410.4
10336610	[1]Upper Truckee River at South Lake Tahoe, CA	24	131.1	208.7	271.2	377.7
		103	128.1	210.5	275.3	382.0
10336626	Taylor Creek near Camp Richardson, CA	11	71.2	98.8	120.5	157.1
10336635	Lake Tahoe Tributary near Meeks Bay	22	1.6	2.4	3.0	4.0
		103				
10336645	General Creek near Meeks Bay, CA	42	35.1	59.3	78.4	110.0
		103	36.7	60.5	79.0	109.0
10336660	Blackwood Creek near Tahoe City, CA	11	67.7	105.7	137.2	192.3
		103	68.7	106.9	138.1	192.1
10336674	Ward Creek below Confluence near Tahoe City, CA	10	35.7	59.1	78.0	110.1
		103	32.1	60.2	81.7	115.2
10336675	Ward Creek at Stanford Trail Crossing near Tahoe City, CA	30	49.1	79.9	105.9	152.4
		103	46.7	82.7	111.0	157.1
10336676	Ward Creek at Highway 89 near Tahoe Pines, CA	12	33.6	61.0	84.8	127.9
		103	34.0	62.0	85.8	128.0
10336693	Wood Creek near Crystal Bay, NV	18	1.71	3.91	5.80	8.9
10336730	Glenbrook Creek at Glenbrook, NV	18	0.80	1.5	2.2	3.4
		103	0.79	1.5	2.2	3.5
10336740	Logan House Creek nr Glenbrook, NV	10	0.26	0.6	1.0	1.6
		103	0.28	0.6	0.9	1.5
10336756	Edgewood Creek Tributary near Daggett Pass. NV	10	0.02	0.1	0.2	0.6
		103	0.02	0.1	0.2	0.5
103367585	Edgewood Creek at Palisade Drive near Kingsbury, NV	12	0.84	1.8	2.7	4.4
103367592	Eagle Rock Creek nr Stateline, NV	40	0.41	0.61	0.76	0.97
		103	0.42	0.63	0.77	0.98
10336770	Trout Creek at USFS RD 12N01 near Meyers, CA	11	11.4	22.4	30.8	43.7
10336775	Trout Creek at Pioneer Trail near South Lake Tahoe, CA	11	12.9	22.3	30.3	44.7
			14.5	23.7	31.1	43.8
10336780	Trout Creek near Tahoe Valley, CA	11	24.1	40.8	54.0	75.8
		103	24.7	41.1	53.8	74.6
	average difference		**-0.01**	**-0.03**	**-0.01**	**0.01**

[1]Systematic period of record (gage record), [2]historic period assigned to 1997 event [3]Percent chance exceedance

Table 12.11 Mixed distribution log_{10}-statistics, 1day annual maximum flows

Watershed	USGS ID	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
BLACKWOOD	10336660	42	103	2.223	0.478	0.33	42	2.324	0.2321	-0.16
EAGLE ROCK	103367592	10	103	0.031	0.2106	-0.11	11	-0.029	0.261	-0.51
EDGEWOOD	103367585	12	103	0.548	0.3075	0.67	12	0.622	0.3754	-0.59
GENERAL	10336645	22	103	1.914	0.3847	0.58	22	2.074	0.2582	-0.19
GLENBROOK	10336730	18	103	0.688	0.3139	0.87	19	0.666	0.5076	0.05
INCLINE	10336700	18	103	1.221	0.2392	0.57	20	1.266	0.3593	-0.21
INCLINE	103366995	12	103	1.004	0.2266	0.55	13	1.179	0.401	-0.12
INCLINE	103366993	12	103	0.786	0.1931	0.69	12	1.136	0.355	-0.41
LOGAN HOUSE	10336740	19	103	0.161	0.3436	-0.33	19	0.288	0.4529	-0.51
TAYLOR	10336626	24	0	2.142	0.5601	0.06	24	2.374	0.16	-0.26
THIRD	10336698	29	103	1.21	0.2604	0.52	30	1.589	0.3111	-0.91
TROUT	10336770	12	103	1.125	0.1928	1.25	12	1.624	0.3244	-0.1
TROUT	10336775	12	103	1.624	0.2984	0.5	12	1.885	0.3685	-0.06
TROUT	10336780	42	103	1.869	0.3348	0.55	42	2.005	0.3364	-0.34
UPPER TRUCKEE	103366092	12	103	2.299	0.3023	0.21	12	2.722	0.3034	-0.13
UPPER TRUCKEE	10336600	26	0	2.373	0.4247	0.32	26	2.612	0.1735	-0.29
UPPER TRUCKEE	10336580	12	103	1.899	0.341	0.04	12	2.42	0.2204	0.02
UPPER TRUCKEE	10336610	27	103	2.529	0.4125	0.29	28	2.682	0.274	-0.33
WARD	10336676	30	103	1.997	0.4505	0.1	30	2.21	0.2966	-0.33
WARD	10336675	10	103	1.883	0.3655	0.12	10	2.297	0.2896	-0.53
WARD	10336674	10	103	1.723	0.3725	0.29	11	2.105	0.2353	-0.69

winter events: (1) systematic record length, (2) historic period, (3) mean, (4) standard deviation, (5) skew coefficient
summer events: (6) systematic record length, (7) mean, (8) standard deviation, (9) skew coefficient

Table 12.12 Mixed distribution $\log_{10}$-statistics, 3day annual maximum flows

Watershed	USGS ID	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
BLACKWOOD	10336660	42	103	2.103	0.4368	0.47	42	2.285	0.2223	-0.24
EAGLE ROCK	103367592	10	103	-0.009	0.2176	-0.02	11	-0.041	0.2578	-0.46
EDGEWOOD	103367585	12	103	0.449	0.3174	0.18	12	0.532	0.3463	-0.41
GENERAL	10336645	22	0	1.846	0.3761	0.56	22	2.019	0.2432	-0.38
GLENBROOK	10336730	18	103	0.596	0.3091	0.47	19	0.624	0.4988	0
INCLINE	10336700	18	103	1.152	0.24	0.14	20	1.243	0.361	-0.26
INCLINE	103366995	12	103	0.959	0.2305	0.3	13	1.154	0.4051	-0.11
INCLINE	103366993	12	103	0.731	0.1788	0.35	12	1.119	0.3667	-0.43
LOGAN HOUSE	10336740	19	103	0.108	0.3386	-0.33	19	0.246	0.4491	-0.52
TAYLOR	10336626	24	0	2.084	0.5278	0.02	24	2.343	0.1586	-0.17
THIRD	10336698	29	103	1.123	0.2207	0.54	30	1.557	0.305	-0.91
TROUT	10336770	12	103	1.045	0.1919	0.83	12	1.601	0.3261	-0.09
TROUT	10336775	12	103	1.515	0.2816	0.58	12	1.861	0.3652	-0.08
TROUT	10336780	42	103	1.795	0.3154	0.55	42	1.988	0.3394	-0.34
UPPER TRUCKEE	103366092	12	103	2.216	0.2695	0.28	12	2.67	0.2929	-0.19
UPPER TRUCKEE	10336600	26	0	2.252	0.386	0.32	26	2.585	0.1723	-0.35
UPPER TRUCKEE	10336580	12	103	1.798	0.3129	-0.16	12	2.375	0.2232	-0.5
UPPER TRUCKEE	10336610	27	103	2.441	0.3687	0.3	28	2.645	0.2791	-0.42
WARD	10336676	30	103	1.888	0.4144	0.23	30	2.16	0.286	-0.38
WARD	10336675	10	103	1.779	0.3422	0.1	10	2.218	0.2828	-0.48
WARD	10336674	10	103	1.617	0.3369	0.21	11	2.04	0.2363	-0.56

winter events: (1) systematic record length, (2) historic period, (3) mean, (4) standard deviation, (5) skew coefficient
summer events: (6) systematic record length, (7) mean, (8) standard deviation, (9) skew coefficient

Table 12.13 Mixed distribution $\log_{10}$-statistics, 7day annual maximum flows

Watershed	USGS ID	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
BLACKWOOD	10336660	42	103	1.974	0.375	0.3	42	2.242	0.2181	-0.28
EAGLE ROCK	103367592	10	103	-0.037	0.2181	-0.07	11	-0.057	0.2537	-0.39
EDGEWOOD	103367585	12	103	0.395	0.3042	-0.14	12	0.474	0.3563	-0.29
GENERAL	10336645	22	103	1.7	0.3062	0.16	22	1.973	0.2182	0.05
GLENBROOK	10336730	18	103	0.52	0.2993	0.13	19	0.587	0.4992	-0.02
INCLINE	10336700	18	103	1.105	0.2136	-0.22	20	1.223	0.3663	-0.28
INCLINE	103366995	12	103	0.908	0.2163	0.01	13	1.132	0.4072	-0.14
INCLINE	103366993	12	103	0.686	0.1755	0.2	12	1.093	0.3748	-0.44
LOGAN HOUSE	10336740	19	103	0.046	0.3386	-0.42	19	0.195	0.4709	-0.53
TAYLOR	10336626	24	0	2.001	0.4839	-0.05	24	2.287	0.1929	-0.58
THIRD	10336698	29	103	1.04	0.1875	0.61	30	1.509	0.3105	-0.91
TROUT	10336770	12	103	0.984	0.1808	0.64	12	1.572	0.3274	-0.11
TROUT	10336775	12	103	1.438	0.2614	0.39	12	1.835	0.3658	-0.1
TROUT	10336780	42	103	1.713	0.2753	0.4	42	1.967	0.3438	-0.36
UPPER TRUCKEE	103366092	12	103	2.114	0.2484	0.11	12	2.611	0.2899	-0.2
UPPER TRUCKEE	10336600	26	0	2.117	0.3335	0.12	26	2.55	0.1772	-0.38
UPPER TRUCKEE	10336580	12	103	1.681	0.2951	-0.32	12	2.329	0.223	-0.66
UPPER TRUCKEE	10336610	27	103	2.335	0.317	0.2	28	2.602	0.2766	-0.4
WARD	10336676	30	103	1.76	0.363	0.08	30	2.108	0.2769	-0.46
WARD	10336675	10	103	1.673	0.2922	-0.01	10	2.152	0.2779	-0.63
WARD	10336674	10	103	1.499	0.2784	-0.06	11	1.99	0.2299	-0.71

winter events: (1) systematic record length, (2) historic period, (3) mean, (4) standard deviation, (5) skew coefficient
summer events: (6) systematic record length, (7) mean, (8) standard deviation, (9) skew coefficient

Table 12.14 Mixed distribution log_{10}-statistics, 10day annual maximum flows

Watershed	USGS ID	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
BLACKWOOD	10336660	42	103	1.921	0.3506	0.21	42	2.218	0.2157	-0.31
EAGLE ROCK	103367592	10	103	-0.045	0.2196	-0.06	11	-0.063	0.2535	-0.35
EDGEWOOD	103367585	12	103	0.374	0.2982	-0.22	12	0.447	0.3683	-0.31
GENERAL	10336645	22	103	1.653	0.287	0.03	22	1.94	0.2175	0.04
GLENBROOK	10336730	18	103	0.491	0.295	-0.03	19	0.564	0.5012	-0.11
INCLINE	10336700	18	103	1.086	0.2042	-0.34	20	1.21	0.3687	-0.26
INCLINE	103366995	12	103	0.892	0.2084	-0.09	13	1.119	0.407	-0.14
INCLINE	103366993	12	103	0.665	0.1706	0.06	12	1.078	0.3756	-0.44
LOGAN HOUSE	10336740	19	0	0.03	0.3461	-0.54	19	0.202	0.4193	-0.15
TAYLOR	10336626	24	0	1.951	0.4574	-0.09	24	2.262	0.1988	-0.59
THIRD	10336698	29	103	1.008	0.178	0.63	30	1.487	0.3153	-0.92
TROUT	10336770	12	103	0.96	0.1729	0.66	12	1.558	0.3262	-0.14
TROUT	10336775	12	103	1.419	0.2522	0.26	12	1.822	0.3654	-0.11
TROUT	10336780	42	103	1.68	0.2565	0.32	42	1.958	0.3451	-0.38
UPPER TRUCKEE	103366092	12	103	2.073	0.2385	0	12	2.583	0.2924	-0.22
UPPER TRUCKEE	10336600	26	0	2.056	0.314	0.03	26	2.531	0.1827	-0.42
UPPER TRUCKEE	10336580	12	103	1.64	0.2827	-0.31	12	2.309	0.2225	-0.73
UPPER TRUCKEE	10336610	27	103	2.292	0.2971	0.14	28	2.577	0.2761	-0.42
WARD	10336676	30	103	1.705	0.3434	0	30	2.084	0.273	-0.46
WARD	10336675	10	103	1.634	0.2818	-0.16	10	2.123	0.2749	-0.74
WARD	10336674	10	103	1.459	0.2623	-0.24	11	1.966	0.2255	-0.77

winter events: (1) systematic record length, (2) historic period, (3) mean, (4) standard deviation, (5) skew coefficient
summer events: (6) systematic record length, (7) mean, (8) standard deviation, (9) skew coefficient

Table 12.15 Mixed distribution log_{10}-statistics, 15day annual maximum flows

Watershed	USGS ID	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
BLACKWOOD	10336660	42	103	1.845	0.3291	0.07	42	2.188	0.2127	-0.27
EAGLE ROCK	103367592	10	103	-0.056	0.2217	-0.05	11	-0.073	0.2528	-0.27
EDGEWOOD	103367585	12	103	0.345	0.2878	-0.28	12	0.424	0.3721	-0.3
GENERAL	10336645	22	103	1.585	0.2747	-0.08	22	1.892	0.2442	-0.41
GLENBROOK	10336730	18	103	0.455	0.2861	-0.14	19	0.537	0.5027	-0.16
INCLINE	10336700	18	103	1.053	0.1907	-0.35	20	1.193	0.3689	-0.26
INCLINE	103366995	12	103	0.863	0.1933	-0.2	13	1.103	0.4052	-0.14
INCLINE	103366993	12	103	0.638	0.1575	-0.09	12	1.056	0.3727	-0.43
LOGAN HOUSE	10336740	19	103	-0.099	0.3112	-0.23	19	0.169	0.4346	-0.22
TAYLOR	10336626	24	0	1.885	0.4223	-0.1	24	2.229	0.2032	-0.61
THIRD	10336698	29	103	0.969	0.1681	0.73	30	1.456	0.3154	-0.86
TROUT	10336770	12	103	0.928	0.163	0.62	12	1.537	0.3212	-0.1
TROUT	10336775	12	103	1.392	0.2397	0.2	12	1.801	0.3656	-0.08
TROUT	10336780	42	103	1.638	0.2392	0.21	42	1.943	0.3435	-0.37
UPPER TRUCKEE	103366092	12	103	2.029	0.2266	-0.06	12	2.542	0.2898	-0.21
UPPER TRUCKEE	10336600	26	0	1.977	0.2971	-0.17	26	2.507	0.1904	-0.42
UPPER TRUCKEE	10336580	12	103	1.591	0.2791	-0.43	12	2.275	0.221	-0.62
UPPER TRUCKEE	10336610	27	103	2.228	0.2805	0.02	28	2.544	0.2752	-0.42
WARD	10336676	30	103	1.633	0.3288	-0.1	30	2.049	0.2665	-0.43
WARD	10336675	10	103	1.588	0.2662	-0.24	10	2.081	0.2706	-0.73
WARD	10336674	10	103	1.413	0.2431	-0.33	11	1.927	0.2229	-0.66

winter events: (1) systematic record length, (2) historic period, (3) mean, (4) standard deviation, (5) skew coefficient
summer events: (6) systematic record length, (7) mean, (8) standard deviation, (9) skew coefficient

Table 12.16 Mixed distribution $\log_{10}$-statistics, 30day annual maximum flows

Watershed	USGS ID	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
BLACKWOOD	10336660	42	103	1.699	0.3033	0.01	42	2.133	0.2175	-0.37
EAGLE ROCK	103367592	10	103	-0.079	0.227	-0.03	11	-0.095	0.2598	-0.17
EDGEWOOD	103367585	12	103	0.283	0.2821	-0.35	12	0.384	0.3779	-0.31
GENERAL	10336645	22	0	1.456	0.2861	0.04	22	1.821	0.2575	-0.44
GLENBROOK	10336730	18	103	0.387	0.2787	-0.29	19	0.495	0.4924	-0.18
INCLINE	10336700	18	103	0.979	0.1853	-0.24	20	1.159	0.367	-0.29
INCLINE	103366995	12	103	0.79	0.1979	-0.34	13	1.064	0.405	-0.19
INCLINE	103366993	12	103	0.556	0.1543	-0.66	12	1.017	0.3725	-0.49
LOGAN HOUSE	10336740	19	0	-0.127	0.3546	-0.4	19	0.096	0.4498	-0.19
TAYLOR	10336626	24	0	1.767	0.3712	-0.06	24	2.157	0.2159	-0.46
THIRD	10336698	29	103	0.889	0.1517	0.46	30	1.392	0.311	-0.82
TROUT	10336770	12	103	0.852	0.1656	0.57	12	1.493	0.3205	-0.09
TROUT	10336775	12	103	1.319	0.2362	0.04	12	1.762	0.3663	-0.13
TROUT	10336780	42	103	1.557	0.2203	0.14	42	1.909	0.3372	-0.35
UPPER TRUCKEE	103366092	12	103	1.914	0.1954	0.04	12	2.489	0.27	-0.24
UPPER TRUCKEE	10336600	26	0	1.832	0.2774	-0.23	26	2.452	0.1966	-0.36
UPPER TRUCKEE	10336580	12	103	1.453	0.2585	-0.72	12	2.219	0.2228	-0.49
UPPER TRUCKEE	10336610	27	103	2.122	0.2692	-0.05	28	2.493	0.2727	-0.44
WARD	10336676	30	103	1.503	0.3132	-0.11	30	1.99	0.2636	-0.53
WARD	10336675	10	103	1.463	0.2364	-0.13	10	2.019	0.2648	-0.91
WARD	10336674	10	103	1.278	0.1969	-0.18	11	1.867	0.212	-0.74

winter events: (1) systematic record length, (2) historic period, (3) mean, (4) standard deviation, (5) skew coefficient
summer events: (6) systematic record length, (7) mean, (8) standard deviation, (9) skew coefficient

Table 12.17: Mixed distribution annual maximum volume duration frequency curves for Lake Tahoe gages [Duration versus exceedance]

Watershed	USGS ID		0.99	0.95	0.9	0.8	0.5	0.2	0.1	0.04	0.02	0.01	0.002
UPPER TRUCKEE	10336580	1day	91	124	148	182	273	414	517	657	769	886	1185
		3day	70	104	128	163	251	370	445	533	592	649	771
		7day	59	90	112	144	226	331	393	463	507	547	627
		10day	55	85	106	138	217	316	373	434	473	508	574
		15day	52	79	98	126	199	291	346	408	449	487	561
		30day	45	68	84	109	173	257	309	371	413	453	537
	10336600	1day	178	239	280	338	482	707	921	1446	2076	2891	5802
		3day	160	217	254	306	432	606	733	967	1288	1739	3273
		7day	139	190	224	270	381	525	616	731	823	924	1334
		10day	127	176	208	253	361	498	582	683	755	825	999
		15day	114	159	189	232	336	471	553	650	718	781	916
		30day	95	134	160	198	292	417	496	591	656	719	857
	103366092	1day	139	207	257	337	572	982	1303	1759	2129	2526	3552
		3day	124	182	226	295	497	842	1103	1466	1750	2050	2807
		7day	106	156	193	251	425	723	948	1257	1498	1752	2381
		10day	98	144	178	233	397	680	891	1181	1405	1639	2214
		15day	90	131	162	210	359	615	806	1065	1268	1479	2000
		30day	80	116	143	187	317	523	672	868	1018	1171	1540
	10336610	1day	157	238	297	387	640	1068	1429	2052	2768	3762	7269
		3day	139	210	263	342	561	909	1167	1556	1926	2427	4348
		7day	125	185	228	294	475	752	948	1208	1409	1623	2209
		10day	117	173	213	274	440	691	867	1093	1262	1434	1856
		15day	107	157	193	248	397	624	781	983	1129	1274	1609
		30day	92	135	166	213	342	541	678	850	975	1096	1376
TAYLOR	10336626	1day	109	145	169	202	289	458	730	1361	2041	2946	6227
		3day	103	135	156	186	263	401	585	1025	1488	2080	4106
		7day	73	106	128	160	236	345	443	690	957	1281	2302
		10day	67	98	118	148	219	317	393	547	736	962	1642
		15day	60	88	107	134	199	284	342	431	537	684	1116
		30day	49	71	86	107	162	235	283	344	392	448	645
GENERAL	10336645	1day	41	60	73	94	151	250	335	489	666	931	1961
		3day	37	54	66	84	132	208	271	386	533	744	1529
		7day	37	49	58	71	105	158	197	252	297	347	484
		10day	34	46	53	65	95	142	176	222	259	298	398
		15day	26	38	45	57	87	131	160	196	222	248	306
		30day	20	30	36	46	73	113	140	173	197	220	273

Table 12.17: Mixed distribution annual maximum volume duration frequency curves for Lake Tahoe gages (continued) [Duration versus exceedance]

Watershed	USGS ID		0.99	0.95	0.9	0.8	0.5	0.2	0.1	0.04	0.02	0.01	0.002
BLACKWOOD	10336660	1day	80	115	140	178	287	499	738	1288	1937	2814	6180
		3day	72	102	124	156	243	391	534	860	1275	1846	4067
		7day	64	90	109	136	205	310	390	517	653	848	1547
		10day	60	85	102	127	190	281	346	439	523	630	1044
		15day	56	78	93	115	171	251	305	376	433	493	679
		30day	45	65	78	97	146	214	258	312	351	389	478
WARD	10336674	1day	38	59	73	94	148	218	264	322	375	466	846
		3day	33	50	61	78	123	183	221	268	303	339	469
		7day	29	43	53	68	106	155	183	215	236	254	291
		10day	27	40	50	64	100	144	170	197	215	231	259
		15day	25	37	45	58	90	131	156	183	201	217	248
		30day	21	32	39	50	78	112	131	151	164	175	197
	10336675	1day	50	80	102	136	230	371	467	590	682	774	1020
		3day	43	66	84	111	186	300	377	475	546	618	790
		7day	36	56	70	93	156	248	307	378	424	469	562
		10day	33	52	66	87	146	229	281	339	376	410	480
		15day	31	48	60	79	132	206	251	303	336	365	424
		30day	25	39	50	67	115	176	210	246	268	286	319
	10336676	1day	47	74	94	125	216	370	494	703	915	1207	2236
		3day	41	64	81	108	181	300	391	530	664	848	1573
		7day	36	56	70	92	151	239	301	382	445	511	710
		10day	34	52	65	85	139	219	273	342	394	445	571
		15day	32	48	59	77	125	195	243	304	347	390	488
		30day	26	40	50	65	107	166	205	253	286	317	384
THIRD	10336698	1day	9.9	15.1	19.2	25.9	45.4	73.0	89.6	108.1	119.3	129.6	147.9
		3day	9.0	13.4	17.0	23.0	40.9	66.1	81.0	97.3	106.9	115.4	131.5
		7day	7.9	11.4	14.4	19.8	36.2	59.5	73.4	88.5	97.4	105.4	120.8
		10day	7.4	10.6	13.4	18.6	34.5	57.1	70.5	85.1	93.6	101.2	115.9
		15day	6.9	9.8	12.3	17.0	31.8	53.2	66.1	80.8	89.6	98.1	112.6
		30day	6.0	8.4	10.5	14.5	27.2	45.5	56.7	69.1	77.2	84.3	97.9
INCLINE	103366993	1day	3.8	5.2	6.4	8.3	15.0	27.7	37.5	50.9	61.0	71.5	97.1
		3day	3.5	4.8	5.9	7.7	14.2	27.1	37.1	50.5	60.8	71.4	96.4
		7day	3.2	4.4	5.4	7.0	13.3	25.9	35.7	48.9	59.2	69.7	94.7
		10day	3.1	4.2	5.2	6.7	12.8	25.1	34.5	47.3	57.3	67.4	91.5
		15day	3.0	4.1	4.9	6.3	12.1	23.7	32.6	44.7	54.2	63.8	86.9
		30day	2.6	3.6	4.3	5.5	11.2	21.7	29.6	40.1	48.0	56.0	74.6

Table 12.17: Mixed distribution annual maximum volume duration frequency curves for Lake Tahoe gages (continued) [Duration versus exceedance]

Watershed	USGS ID		0.99	0.95	0.9	0.8	0.5	0.2	0.1	0.04	0.02	0.01	0.002
INCLINE	103366995	1day	5.1	7.0	8.4	10.7	18.3	34.7	49.9	74.0	95.5	120.0	189.9
		3day	4.6	6.4	7.7	9.9	17.1	32.5	47.2	70.7	91.7	115.8	184.3
		7day	4.2	5.9	7.2	9.2	15.6	30.3	44.5	67.0	86.8	109.2	172.6
		10day	4.1	5.8	7.0	8.9	15.0	29.3	43.1	64.9	84.2	106.0	167.5
		15day	4.0	5.6	6.7	8.4	14.0	28.0	41.3	62.0	80.2	100.9	158.7
		30day	3.4	4.9	5.9	7.5	12.6	25.6	37.5	55.7	71.5	89.0	137.2
	10336700	1day	7.8	10.4	12.4	15.6	25.1	42.9	57.7	79.5	98.0	118.1	172.4
		3day	6.6	9.3	11.3	14.3	23.1	38.8	51.9	71.0	87.0	104.0	148.9
		7day	6.3	8.9	10.7	13.4	21.0	35.3	48.1	67.5	83.2	100.1	143.2
		10day	6.1	8.7	10.4	12.9	20.0	33.9	46.9	66.2	82.0	99.0	142.6
		15day	5.9	8.2	9.8	12.1	18.7	32.3	45.2	63.9	79.3	95.8	138.4
		30day	5.2	7.2	8.6	10.6	16.7	29.7	41.4	58.0	71.4	85.7	121.9
GLENBROOK	10336730	1day	1.8	2.5	3.0	4.0	7.5	16.1	25.3	42.1	59.5	81.8	158.8
		3day	1.4	2.1	2.6	3.5	6.5	13.5	20.7	33.6	46.6	62.9	116.8
		7day	1.2	1.8	2.3	3.1	5.7	11.6	17.8	29.2	40.7	55.2	102.6
		10day	1.1	1.7	2.2	3.0	5.4	10.8	16.4	26.6	36.7	48.9	86.9
		15day	1.0	1.6	2.1	2.8	5.1	10.0	15.1	24.5	33.5	44.3	76.9
		30day	0.9	1.5	1.9	2.5	4.4	8.6	13.1	21.2	28.6	37.5	63.5
LOGAN HOUSE	10336740	1day	0.50	0.86	1.13	1.56	2.88	5.27	7.24	10.10	12.43	14.86	21.03
		3day	0.46	0.77	1.02	1.40	2.58	4.70	6.45	8.96	10.99	13.11	18.19
		7day	0.39	0.67	0.89	1.23	2.29	4.27	5.96	8.52	10.54	12.69	17.84
		10day	0.37	0.61	0.80	1.44	2.17	3.94	5.54	8.22	10.37	13.55	17.82
		15day	0.35	0.56	0.72	0.98	1.82	3.57	5.23	7.89	10.25	12.91	17.81
		30day	0.29	0.48	0.64	0.88	1.66	3.21	4.68	7.15	9.42	12.02	17.80
EDGEWOOD	103367585	1day	1.45	2.10	2.62	3.45	6.01	10.49	13.92	18.79	22.85	27.90	48.40
		3day	1.15	1.74	2.17	2.84	4.81	8.10	10.65	14.14	16.97	20.01	28.45
		7day	1.01	1.54	1.93	2.52	4.20	7.03	9.22	12.30	14.80	17.45	24.18
		10day	0.95	1.46	1.82	2.39	3.99	6.67	8.77	11.77	14.23	16.87	23.76
		15day	0.90	1.38	1.73	2.26	3.74	6.23	8.22	11.10	13.52	16.13	23.00
		30day	0.80	1.23	1.54	2.01	3.33	5.57	7.41	10.16	12.48	14.97	21.31
EAGLE ROCK	103367592	1day	0.51	0.69	0.80	0.97	1.38	1.94	2.31	2.76	3.10	3.43	4.20
		3day	0.47	0.64	0.74	0.90	1.29	1.84	2.21	2.68	3.03	3.38	4.10
		7day	0.45	0.60	0.71	0.85	1.22	1.75	2.10	2.55	2.88	3.21	4.00
		10day	0.44	0.59	0.69	0.84	1.20	1.72	2.08	2.53	2.87	3.20	3.99
		15day	0.43	0.58	0.67	0.81	1.17	1.69	2.05	2.51	2.86	3.19	3.98
		30day	0.40	0.54	0.63	0.77	1.12	1.64	2.01	2.50	2.85	3.18	3.97

Table 12.17: Mixed distribution annual maximum volume duration frequency curves for Lake Tahoe gages (continued)

Watershed	USGS ID		0.99	0.95	0.9	0.8	0.5	0.2	0.1	0.04	0.02	0.01	0.002
TROUT	10336770	1day	10	14	18	24	43	80	109	152	188	228	333
		3day	9	13	16	22	41	75	104	145	180	217	318
		7day	8	12	15	20	38	71	97	136	168	202	295
		10day	8	11	15	20	37	68	94	130	159	192	276
		15day	8	11	14	19	35	64	88	123	151	182	265
		30day	7	10	12	17	31	58	80	111	137	165	240
TROUT	10336775	1day	21	31	39	51	91	171	240	348	443	551	859
		3day	18	27	34	45	81	155	218	315	400	496	763
		7day	17	24	30	41	74	142	201	292	370	458	702
		10day	16	24	30	39	71	137	194	280	355	438	666
		15day	15	23	28	37	67	130	185	270	344	427	659
		30day	14	20	25	33	61	118	168	244	308	380	574
TROUT	10336780	1day	32	48	59	78	135	236	316	435	541	671	1130
		3day	29	43	54	71	124	215	288	391	478	574	867
		7day	27	39	49	64	111	193	257	346	414	487	666
		10day	26	38	47	61	106	185	247	332	398	466	631
		15day	25	36	44	58	99	175	235	317	380	445	605
		30day	22	32	39	51	88	158	213	287	345	404	549